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Failure Analysis of Vibration Test Cards for Crane Job ID: TOL0901051

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Revision History			
Revision	**Created by**	**Date**	**Short Description**
1	**Eva Kosiba**	**Nov 27, 2009**	**Initial Version**

EXECUTIVE SUMMARY

A set of 9 Crane/Nasa-DoD vibration test vehicles were submitted to Celestica's Performance Innovation Laboratories for physical failure analysis. The samples were SMT assembled with Pb-free solder. A subset of the leaded components was then hand soldered (reworked) with SnPb solder. The vibration testing resulted in electrical failures in over 80% of all components. See separate report on vibration test results titled "TOL0901051 Crane Vibration Report.pdf". In total, 63 components on each board were in-situ resistance monitored during the vibration testing. An average of 51 components failed electrically on each board.

Out of the 9 boards, 33 parts, all representing electrical failures, were selected for cross-sectioned. The cross-sections revealed a high degree of damage throughout the solder joints. This damage occurred across all cross-sectioned parts and did not seem to correlate to the part type, location on the board or type of solder, i.e. no significant difference between the Pb-free (non-reworked) parts and the reworked SnPb parts.

Interestingly, cross sectioning revealed cracks in the actual copper leads of the TQFP-144 packages. This damage was observed only on parts which were not reworked and therefore the solder joint was Pb-free. This is to be expected as the Pb-free solder is stiffer than the SnPb solder and transfers the stress to the weaker copper leads. Comparatively, the alloy 42 lead frame parts all failed in the solder as opposed to the leads. In 7 cases the solder failed completely and the intact parts actually fell off the boards during vibration testing.

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1. INTRODUCTION

1.1 PRODUCT INFORMATION

Nine populated test boards were provided to Celestica. All nine boards had an immersion silver surface finish on Isola 370HR laminate, and were processed using a SAC305 reflow alloy and SN100C wave solder alloy. A number of components on each test board were then hand reworked using Kester 66/285 SnPb solder (a 63Sn 37Pb solder) either one or two times. The components which were tested from the nine boards had termination finishes of SAC305, Pure Tin (Sn) or Tin-Bismuth (SnBi).

All nine samples were then subjected to vibration testing of 8Grms for a 1 hour duration followed by 10Grms, 12Grms, 14Grms, 16Grms, 18Grms, 20Grms and 28Grms each for one hour or until failure. Full details on the vibration tests can be found in "TOL0901051 Crane Vibration Report.pdf".

This report focuses on the physical failure analysis that was performed upon the completion of the vibration tests. The focus is to compare the quality of the solder joint of components that were reworked using various solder alloys with those which were not reworked at all. Both leaded and leadless components were examined in this analysis.

1.2 DESCRIPTION OF TEST

The following matrix is a summary of components which were evaluated by cross sectioning. These were selected by the project team after the completion of Weibull analysis. Twelve outliers, six bad fit and 22 reworked components were selected for analysis. Of these 40 initially selected parts, 7 fell off of the boards during vibration testing and as a result not cross-sectioned. This left 33 parts in total for cross-sectioning.

Card	Style										
	CLCC-20	QFN-20		TQFP-144			TSOP-50				
SN61		U28**		U20				U16**	U29*		U62*
SN62					U31*					U61	
SN63	U52		U54*	U20	U31**	U41		U16**		U61*	
SN64											U62
SN65	U52	U28**	U54*	U20		U41	U12		U29*	U61*	U62*
SN66										U61	U62
SN67	U52		U54*		U31**		U12			U61*	U62*
SN68		U28*			U31*			U16*	U29**		
SN79		U28*					U12	U16*	U29**		

Table 1: Component Test Summary

** represents one rework performed*
*** represents two reworks performed*

Components which are underlined fell of the board during vibration testing and where therefore not cross sectioned
All of the above components failed electrically.

The locations of the cross-sectioned components are illustrated in figure 1 (multiple parts per location)

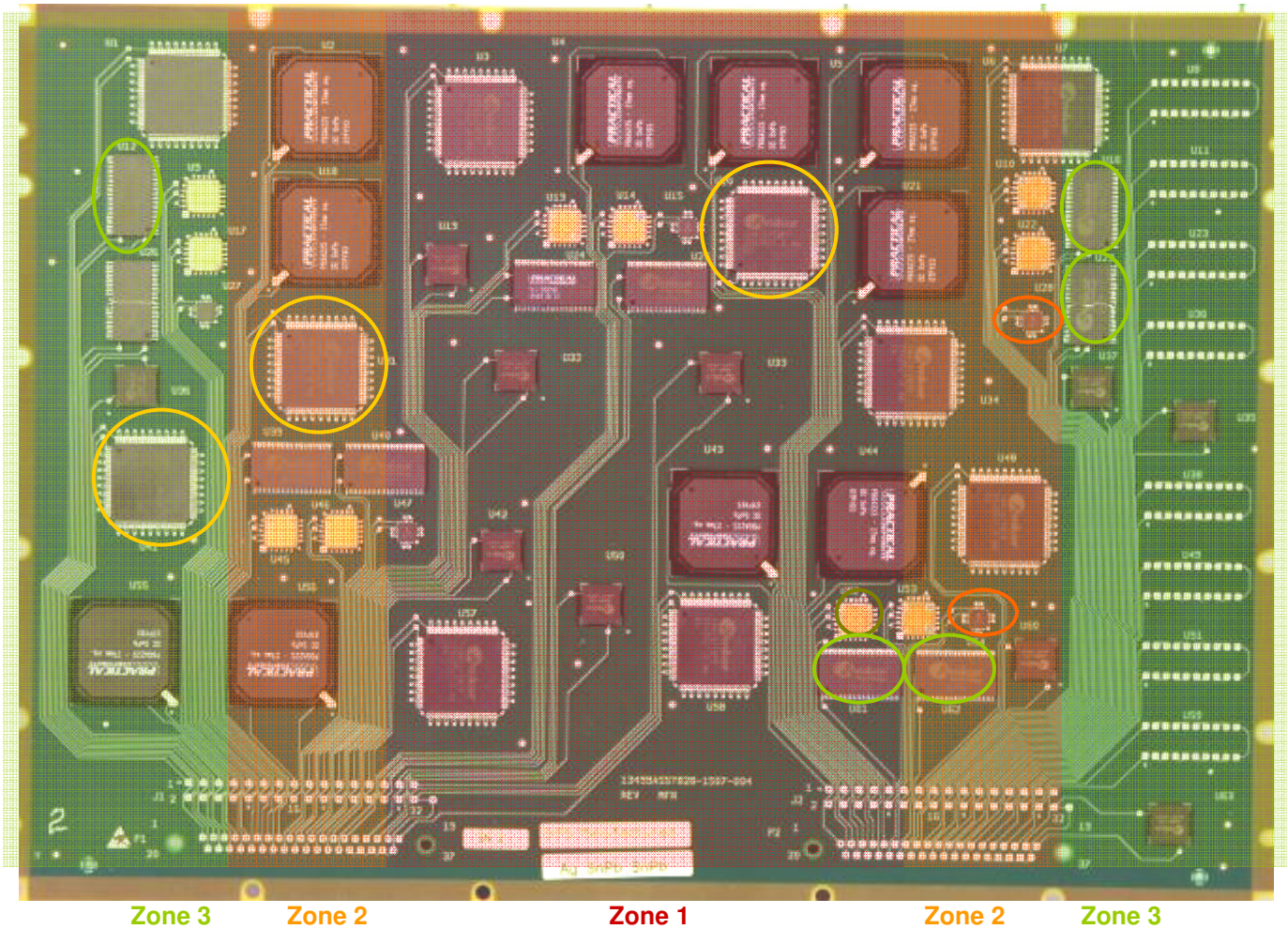

Figure 1: Component Location

The components which were evaluated via cross sectioning where then potted (using LECOSET 100), ground with papers, and polished according to Celestica's cross-sectioning procedure. They were then evaluated using an optical microscope.

2. TEST SPECIFICATIONS

Name	Reference #	Level/Control
Cross-section Analysis	CELQ-001-PROC-450	Rev.15

3. INSTRUMENTATION

Description	Serial Number	Calibration Due Date
Olympus Stereo Microscope – SZX-12	n/a	n/a
Nikon MM-11 microscope	M7572	Calibrate before use

4. ANALYSTS

Name	Employee #	Title
Polina Snugovsky	07097117	Senior Metallurgist
Jason Bragg	07095810	Operations Engineering Advisor
Jie Qian	07002409	Metallurgical Analyst
Eva Kosiba	07005073	Operations Engineering Advisor

5. RESULTS AND COMMENTS

5.1 Cross Sectioning

Of the 40 components which were selected for cross sectioning seven parts fell off during testing and were therefore not cross sectioned. The remaining 33 all failed electrically during vibration testing. Tables two through five show the results of both the vibration testing and the observations made during cross sectioning.

Card	Site	Sample Characteristics				Results of Vibration Test		Cross Sectioning Results			
								Leads		Solder	
		Style	Finish	Solder	Reworks	Tf	Gs	Right	Left	Right	Left
SN63	U52	CLCC-20	SAC305	SAC305	0	421	28	N/A	N/A	cracked	cracked
SN65	U52	CLCC-20	SAC305	SAC305	0	121	12	N/A	N/A	cracked	cracked
SN67	U52	CLCC-20	SAC305	SAC305	0	421	28	N/A	N/A	cracked	cracked

Table 2: Cross Section Observations of CLCC-20

All of the tested CLCC-20s had SAC305 finishes and were located in zone 1. None of these solder joints were reworked. Solder cracks we observed around every solder joint as illustrated in figures 2 to 5.

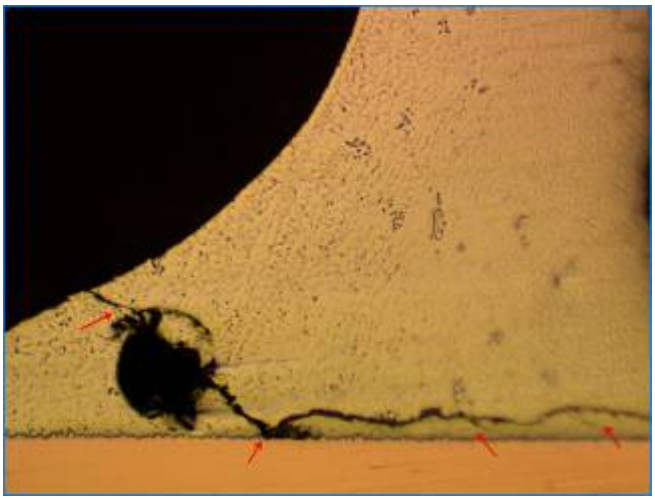

Figure 2: SN67 U52, Left side pad

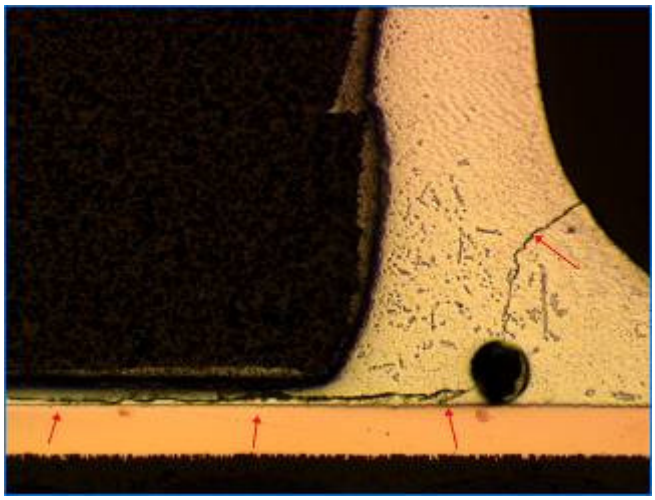

Figure 3: SN67 U52, Right side pad

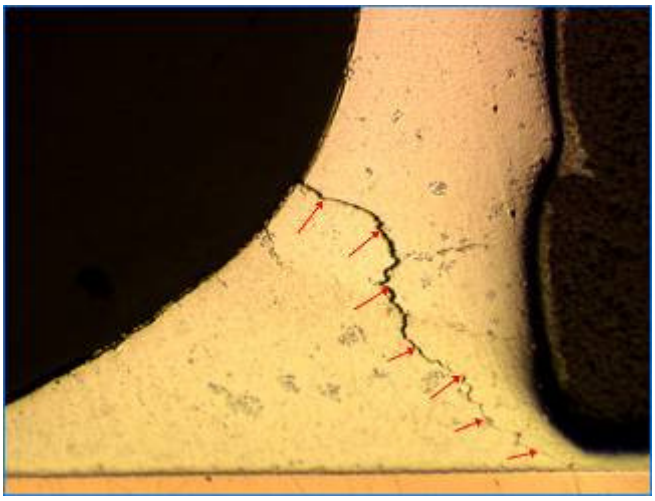

Figure 4: SN63 U52, left side pad

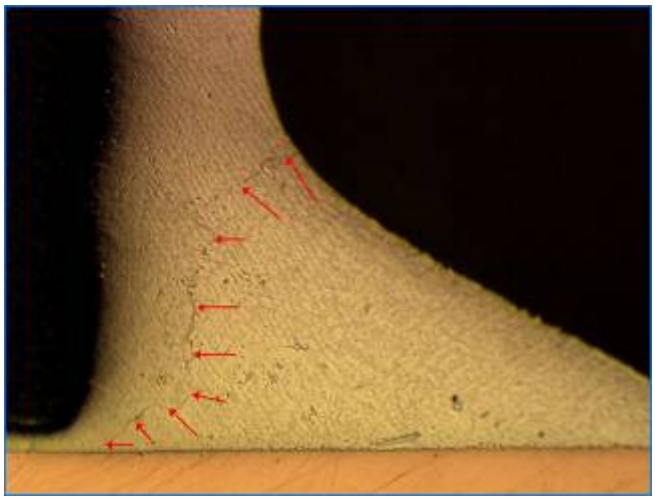

Figure 5: SN63 U52, right side pad

The cross sections of all CCLC-20 packages were performed on corner pads. Each cross section revealed cracking across the length of the solder. SN67 also showed voiding. In this case the crack traveled along the void.

Card	Site	Sample Characteristics				Results of Vibration Test		Cross Sectioning Results			
								Leads		Solder	
		Style	Finish	Solder	Reworks	Tf	Gs	Right	Left	Right	Left
SN63	U54	QFN-20	Sn	SAC305	1	424	28	N/A	N/A	cracked	cracked
SN65	U54	QFN-20	Sn	SAC305	1	115	10	N/A	N/A	--	cracked
SN67	U54	QFN-20	Sn	SAC305	1	465	28	N/A	N/A	cracked	cracked
SN68	U28	QFN-20	Sn	SAC305	1	408	20	N/A	N/A	cracked	--
SN79	U28	QFN-20	Sn	SAC305	1	435	28	N/A	N/A	--	cracked
SN61	U28	QFN-20	Sn	SAC305	2	450	28	N/A	N/A	--	cracked
SN65	U28	QFN-20	Sn	SAC305	2	368	20	N/A	N/A	--	--

Table 3: Cross Section Observations of QFN-20

All of the QFN-20 packages were fabricated using Sn finish and were exposed to one or two re-works with SnPb solder. Approximately half of the solder joints exhibited cracks which ran along the component pad as in figures 6 to 7. There does not appear to be a correlation between the cracked solder and the number of re-work cycles to which the part was exposed.

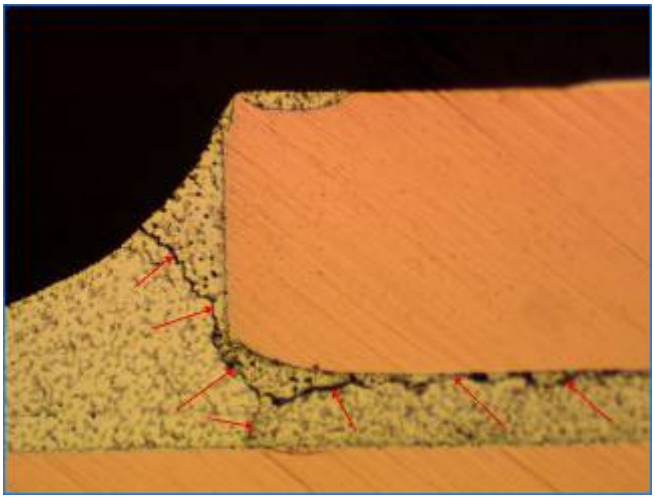

Figure 6: SN63 U54, Left side pad

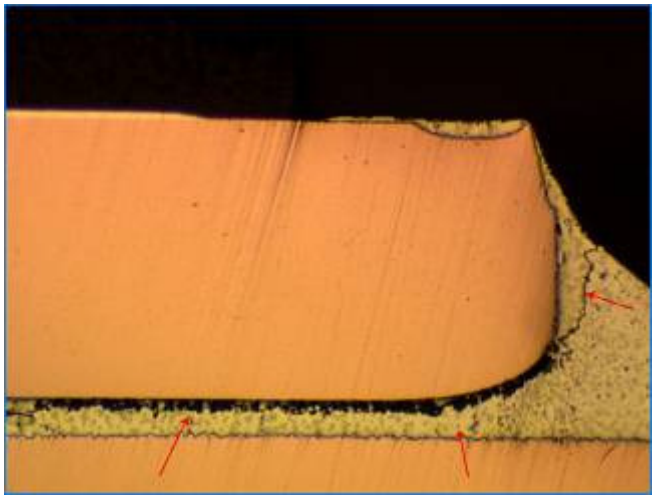

Figure 7: SN68 U28, Right side pad

Cross sections of the QFN-20 packages reveal that the cracks propagated along the component pad.

Card	Site	Sample Characteristics				Results of Vibration Test		Cross Sectioning Results			
								Leads		Solder	
		Style	Finish	Solder	Reworks	Tf	Gs	Right	Left	Right	Left
SN61	U20	TQFP-144	Sn	SAC305	0	246	16	broken	broken	cracked	craked
SN63	U20	TQFP-144	Sn	SAC305	0	121	12	broken	broken	cracked	cracked
SN65	U20	TQFP-144	Sn	SAC305	0	62	10	broken	broken	cracked	cracked
SN63	U41	TQFP-144	Sn	SAC305	0	449	28	--	broken	cracked	cracked
SN65	U41	TQFP-144	Sn	SAC305	0	332	18	--	broken	cracked	cracked
SN62	U31	TQFP-144	Sn	SAC305	1	351	18	--	--	cracked	cracked
SN68	U31	TQFP-144	Sn	SAC305	1	452	28	--	--	cracked	cracked
SN63	U31	TQFP-144	Sn	SAC305	2	433	28	--	--	cracked	cracked
SN67	U31	TQFP-144	Sn	SAC305	2	375	20	--	--	cracked	cracked

Table 4: Cross Section Observations of TQFP-144

All of the TQFP-144 packages were fabricated using Sn finish on the leads, and four of the nine were exposed to one or two re-work cycles with SnPb solder. All of the solder joints experienced significant cracking. Additionally, eight leads broke, all corresponding to components that did not undergo any re-work and therefore contained only Pb-free solder.

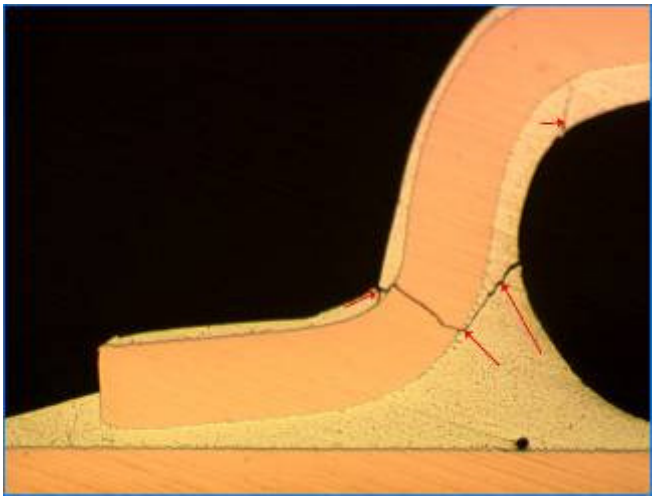

Figure 8: SN63 U41. Left lead

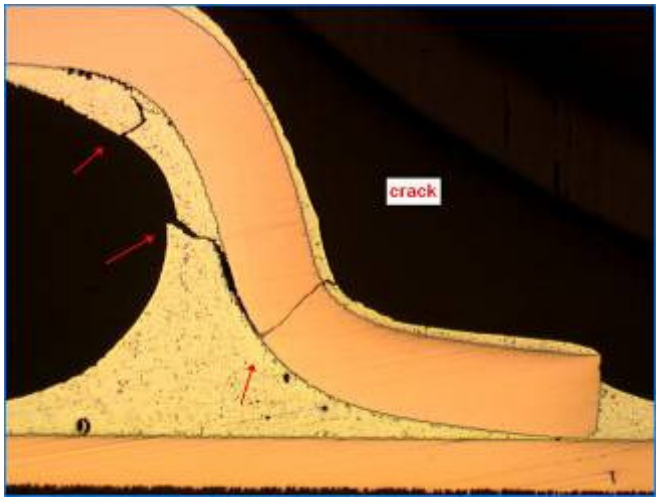

Figure 9: SN61 U20 Right lead

SN63 U41 and SN61 U20 illustrate TQFP-144 packages which were not reworked and therefore contain only Pb-free solders. All of the components experienced broken leads on at least one side of the component, usually both.

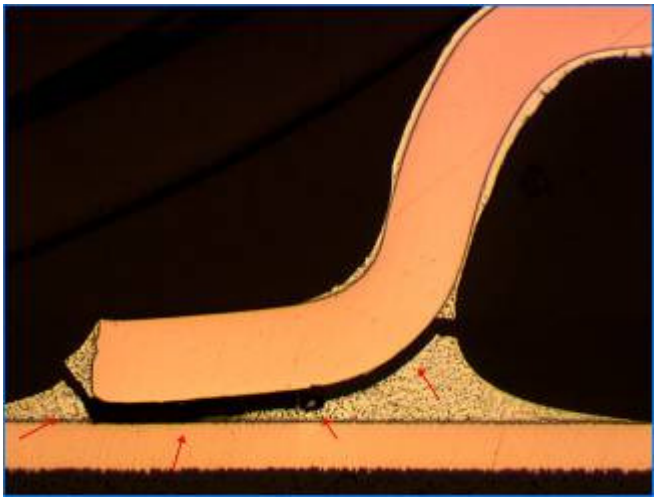

Figure 10: SN67 U31 Left lead

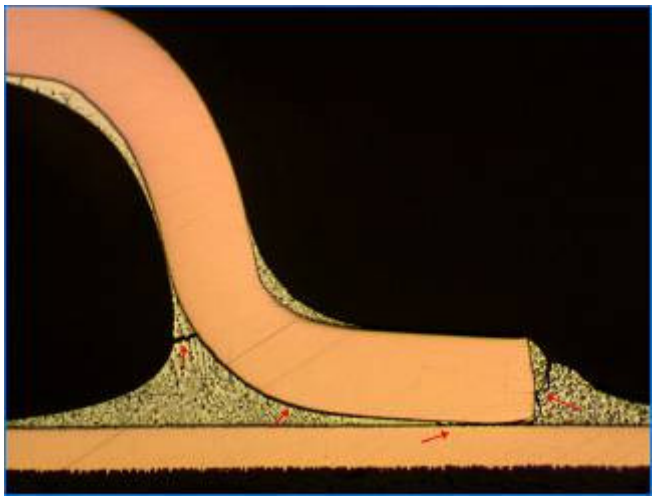

Figure 11: SN68 U31, Right lead

Cross sections of TQFP-144 packages which were re-worked, either once or twice, cracked solder joints in all cases. All of the leads, however, in these samples survived.

Card	Site	Sample Characteristics				Results of Vibration Test		Cross Sectioning Results			
								Leads		Solder	
		Style	Finish	Solder	Reworks	Tf	Gs	Right	Left	Right	Left
SN62	U61	TSOP-50	Sn	SAC305	0	466	28	--	--	cracked	cracked
SN65	U12	TSOP-50	Sn	SAC305	0	334	18	***Part fell of during test***			
SN66	U61	TSOP-50	Sn	SAC305	0	429	28	--	--	cracked	cracked
SN67	U12	TSOP-50	Sn	SAC305	0	181	14	***Part fell of during test***			
SN79	U12	TSOP-50	Sn	SAC305	0	423	28	--	--	cracked	cracked
SN61	U29	TSOP-50	Sn	SAC305	1	424	28	***Part fell of during test***			
SN63	U61	TSOP-50	Sn	SAC305	1	421	28	--	--	cracked	cracked
SN65	U29	TSOP-50	Sn	SAC305	1	327	18	***Part fell of during test***			
SN65	U61	TSOP-50	Sn	SAC305	1	121	12	--	--	cracked	cracked
SN67	U61	TSOP-50	Sn	SAC305	1	337	18	--	--	cracked	cracked
SN68	U29	TSOP-50	Sn	SAC305	2	449	28	--	--	cracked	--
SN79	U29	TSOP-50	Sn	SAC305	2	409	20	***Part fell of during test***			
SN64	U62	TSOP-50	SnBi	SAC305	0	476	28	--	--	--	cracked
SN66	U62	TSOP-50	SnBi	SAC305	0	454	28	--	--	cracked	cracked
SN61	U62	TSOP-50	SnBi	SAC305	1	454	28			cracked	cracked
SN65	U62	TSOP-50	SnBi	SAC305	1	115	10	--	--	cracked	cracked
SN67	U62	TSOP-50	SnBi	SAC305	1	414	20	--	--	cracked	cracked
SN68	U16	TSOP-50	SnBi	SAC305	1	414	20	--	--	cracked	cracked
SN79	U16	TSOP-50	SnBi	SAC305	1	345	18	***Part fell of during test***			
SN61	U16	TSOP-50	SnBi	SAC305	2	361	20	***Part fell of during test***			
SN63	U16	TSOP-50	SnBi	SAC305	2	434	28	--	--	cracked	cracked

Table 5: Cross Section Observations of TSOP-50

Of the twenty one TSOPs tested, seven fell off of the board during the vibration test and where therefore not cross sectioned. All of these parts were in zone 3, closest to the edge of the board. Among the cross sectioned parts, all of the leads remained in tact however almost all of the solder joints experienced significant cracking. The TSOPs had finishes of either Sn or SnBi, and two thirds were re-worked either one or two times using SnPb solder. There does not appear to be any correlation between the lead finish or the number of re-works with the incident of cracking in the solder joint.

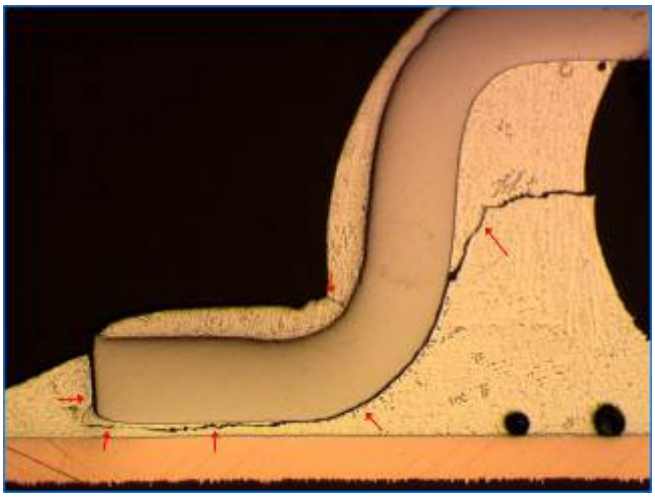

Figure 12: SN79 U12, Left lead

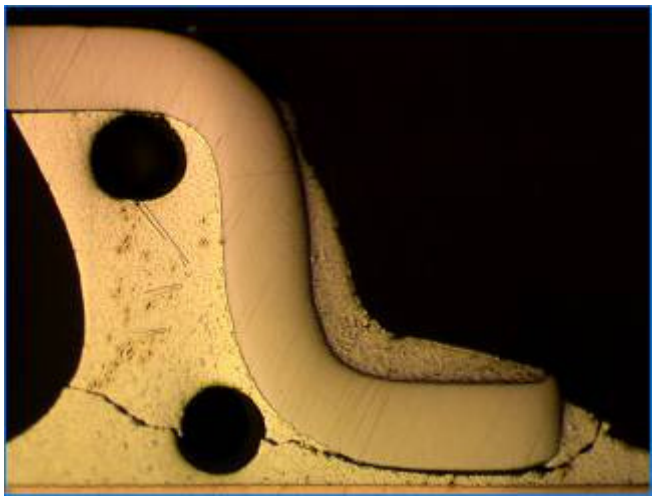

Figure 13: SN66 U62, Right lead

Samples SN79 U12 and SN66 U62 are examples of TSOPs which did not undergo any re-work. They have Sn and SnBi finishes respectively. Both experienced sever solder cracking in leads on both sides of the component.

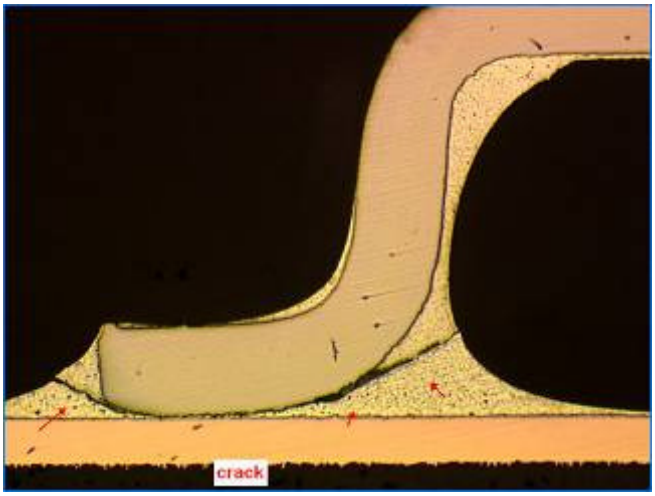

Figure 14: SN65 U62, Left lead

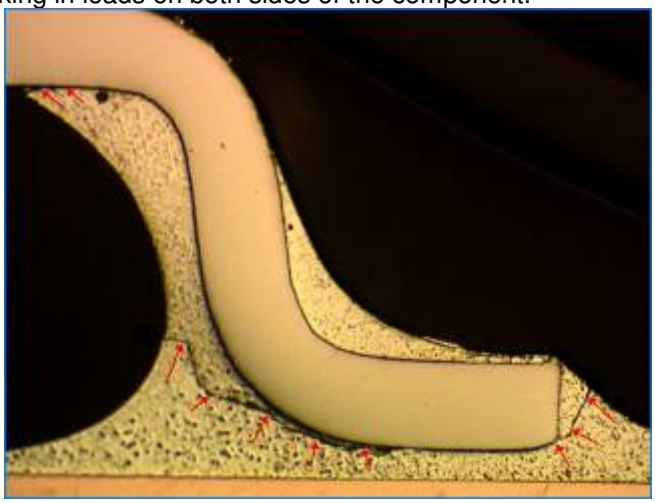

Figure 15: SN63 U61, Right lead

Samples SN63 U61 and SN65 U62 are examples of parts which underwent one re-work cycle with SnPb solder. They have Sn and SnBi finishes respectively and both components showed significant cracking within the solder at both sides of the component. This is consistent with all parts which have undergone one re-work cycle.

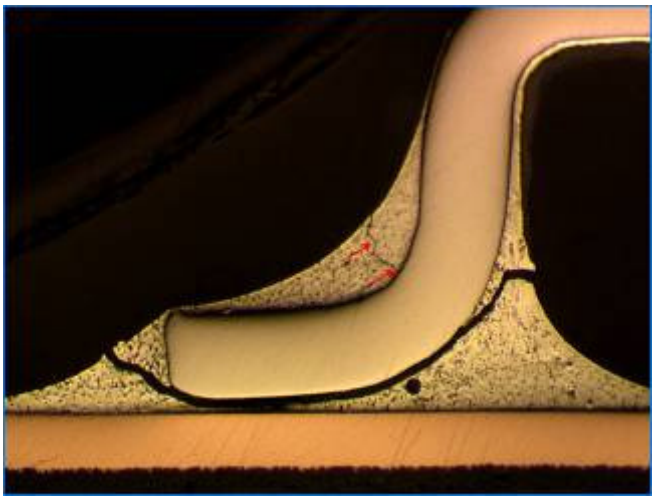

Figure 16: SN63 U16, Left lead

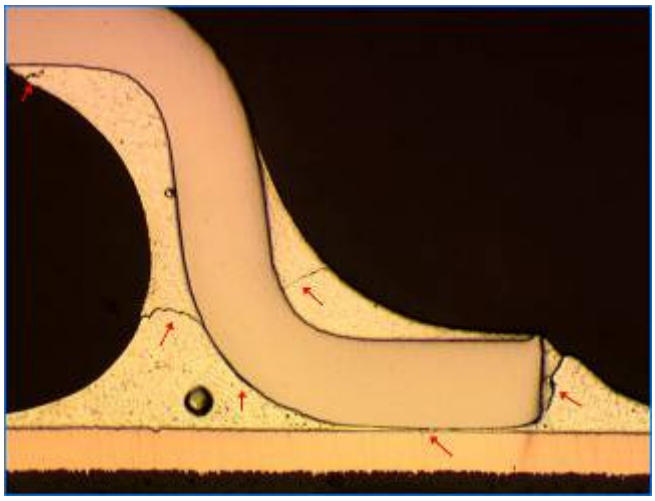

Figure 17: SN68 U29, Right lead

Samples SN68 U29 and SN63 U16 were both re-worked twice with SnPb solder. SN68 U29 is finished with Sn and SN63 U16 is finished with SnBi. The SnBi part experienced extensive solder cracking through-out. The Sn finished part experienced solder cracking at one side of the component.

Based on this limited number of cross sectioned samples, there does not appear to be a correlation between component lead finish and the damage to the leads or bulk solder. The TQFPs show some correlation to number of re-work cycles and damaged leads, as only those leads which did not undergo any re-work broke. As the re-work solder was SnPb, this would indicate that the leads with Pb-free solder joints broke, while those with some Pb in the solder survived.

6. SUMMARY

A set of 9 Crane/Nasa-DoD vibration test vehicles were submitted to Celestica's Performance Innovation Laboratories for physical failure analysis. The samples were SMT assembled with Pb-free solder. A subset of the leaded components was then hand soldered (reworked) with SnPb solder. 63 components were monitored on each of the nine boards during the vibration testing. An average of 51 components failed electrically on each board. 33 parts were selected across the nine boards for cross sectioning, all of which represented electrical failures.

After cross sectioning, extensive cracking in the solder was viewed on all packages for parts which were re-worked (Pb solder) and those which were not (Pb-free solder).

In addition to solder cracks, the TQFP-144s also experienced fracture in the leads of the non-reworked parts (Pb-free solder). The re-worked parts, which extensively damaged through the solder, did not show any fracture in the leads. This is expected due to the greater ductility of the Pb solder.

APPENDIX

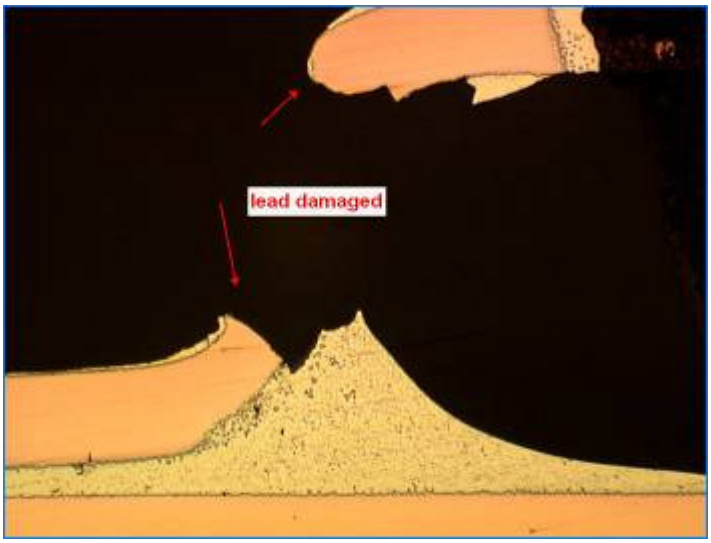

Figure 18: cross section, SN61, U20, left lead damaged, 100x

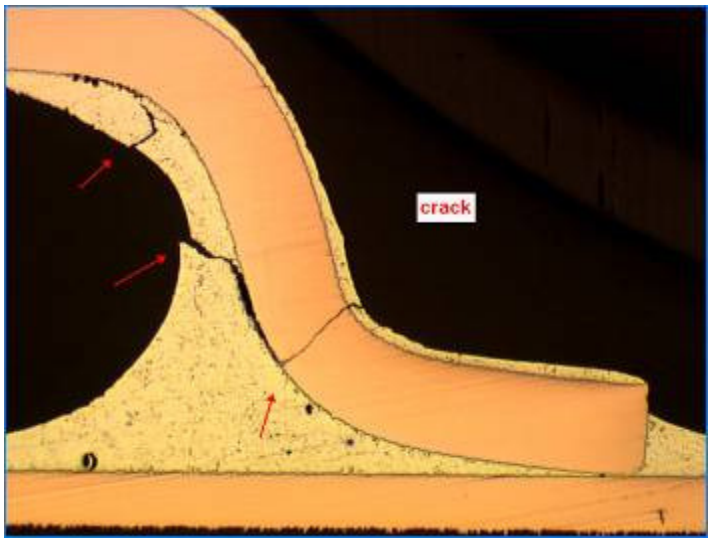

Figure 19: cross section, SN61, U20, right lead and solder crack, 100x

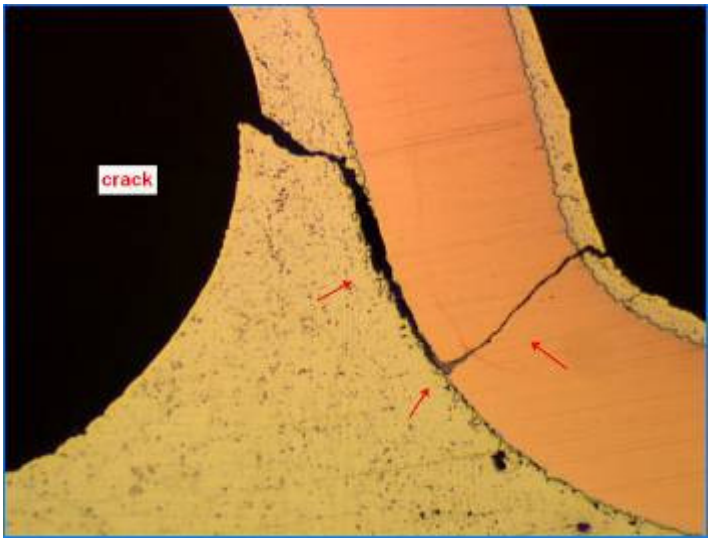

Figure 20: cross section, SN61, U20, right lead and solder crack, 200x

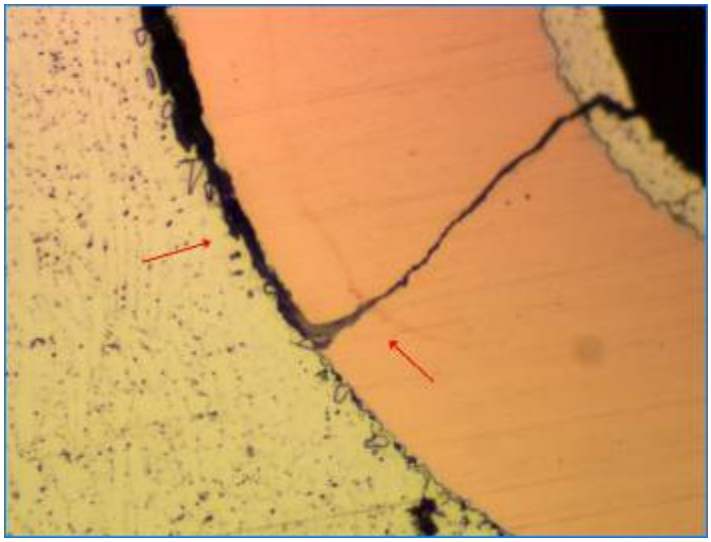

Figure 21: cross section, SN61, U20, right lead and solder crack, 400x

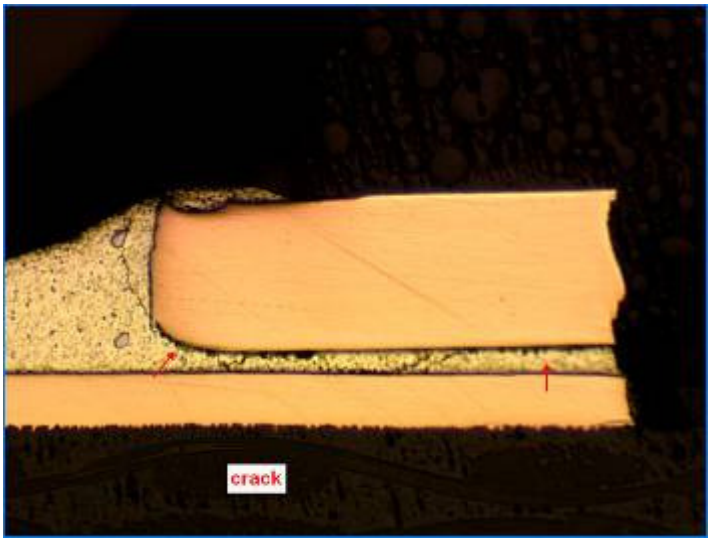

Figure 22: cross section, SN61, U28, left lead solder crack, 100x

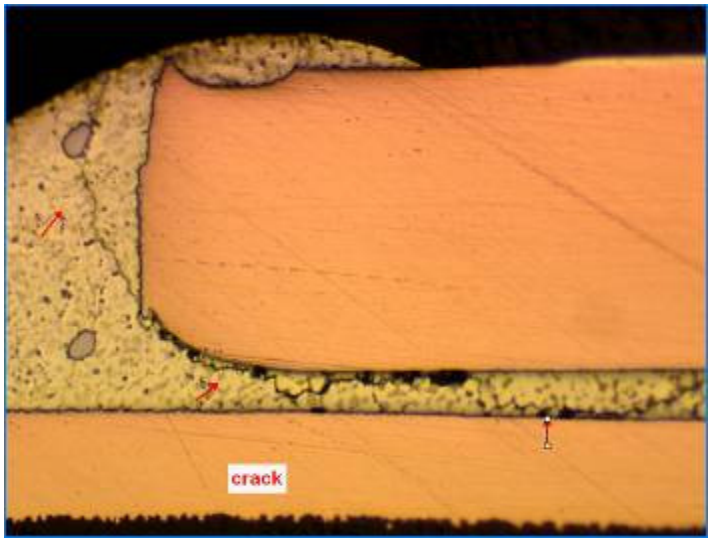

Figure 23: cross section, SN61, U28, left lead solder crack, 200x a

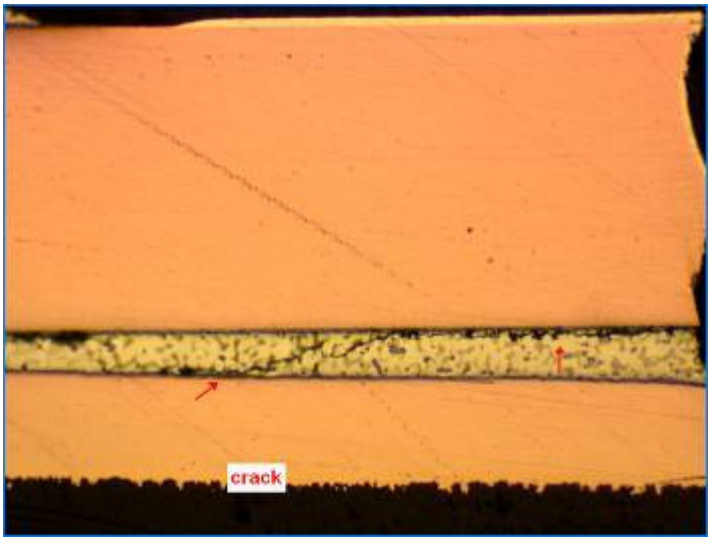

Figure 24: cross section, SN61, U28, left lead solder crack, 200x b

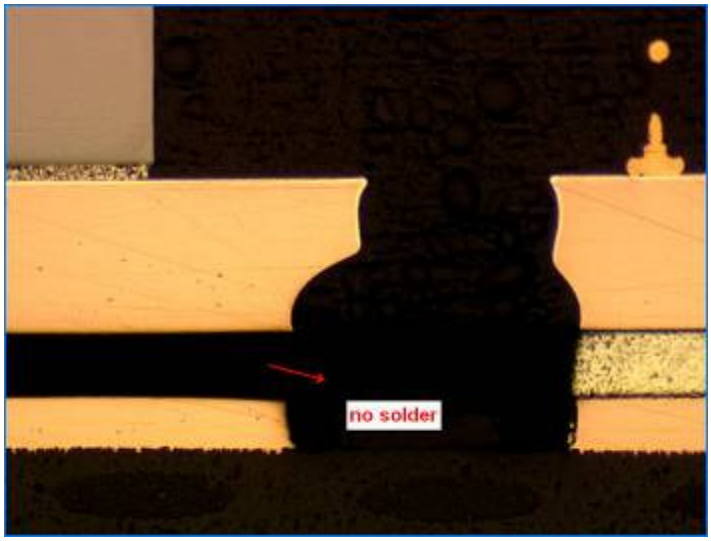

Figure 25: cross section, SN61, U28, middle right side, no solder 100x

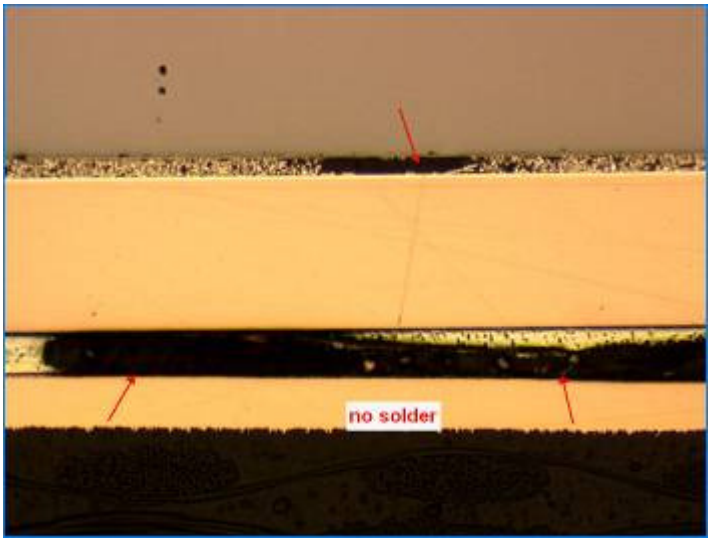

Figure 26: cross section, SN61, U28, middle side, partial solder 100x

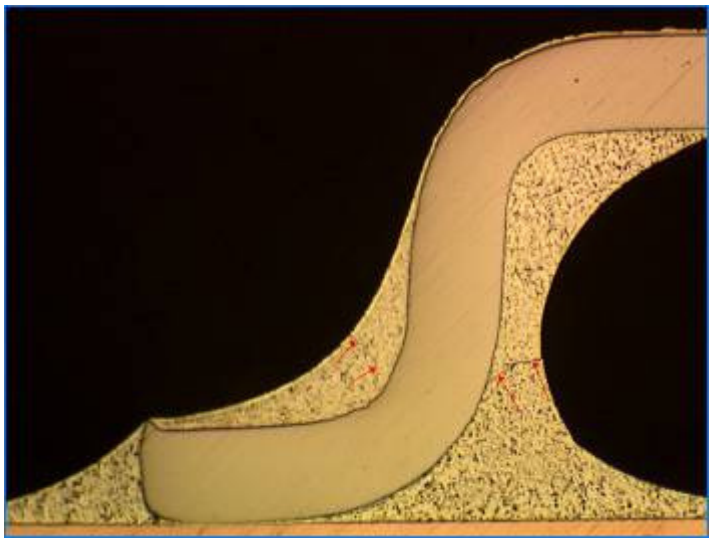

Figure 27: cross section, SN61, U62, left lead, solder crack, 100x

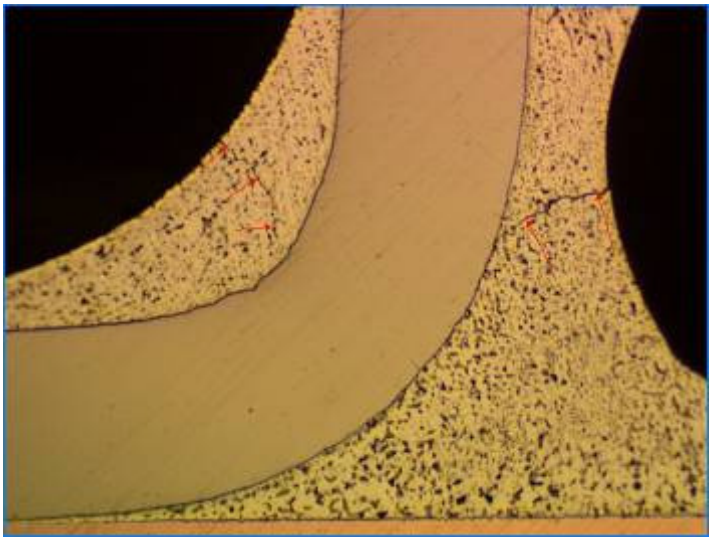

Figure 28: cross section, SN61, U62, left lead, solder crack, 200x

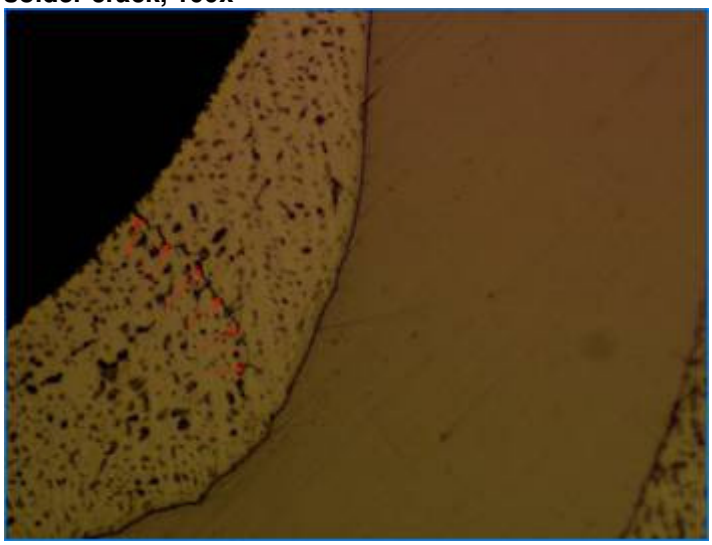

Figure 29: cross section, SN61, U62, left lead, solder crack, 400x

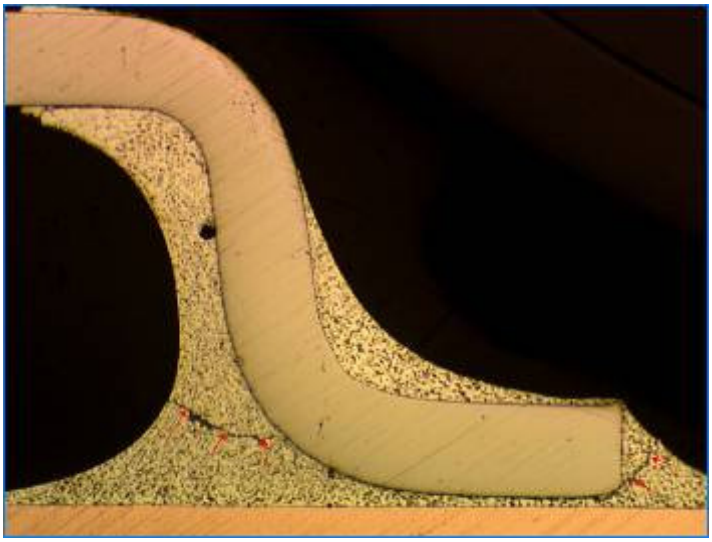

Figure 30: cross section, SN61, U62, right lead, solder crack, 100x

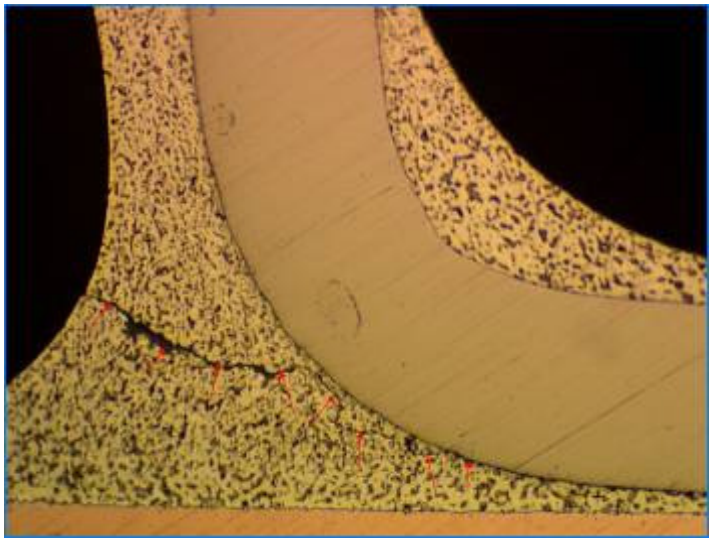

Figure 31: cross section, SN61, U62, right lead, solder crack, 200x

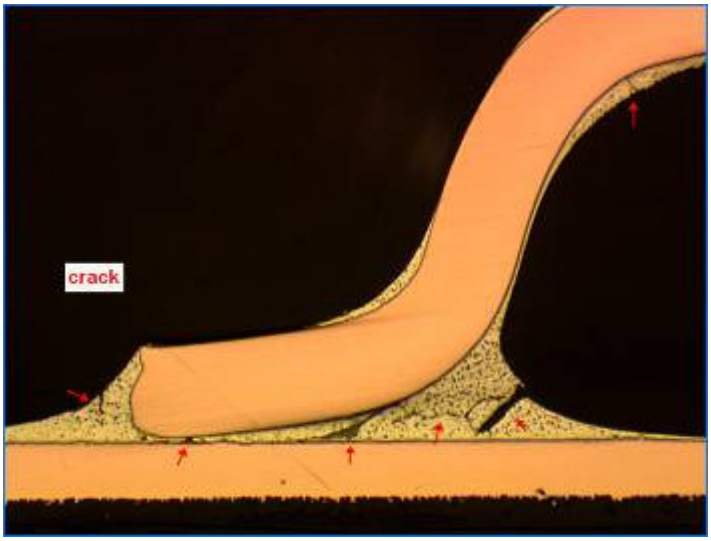

Figure 32: cross section, SN62, U31, left lead solder crack, 100x

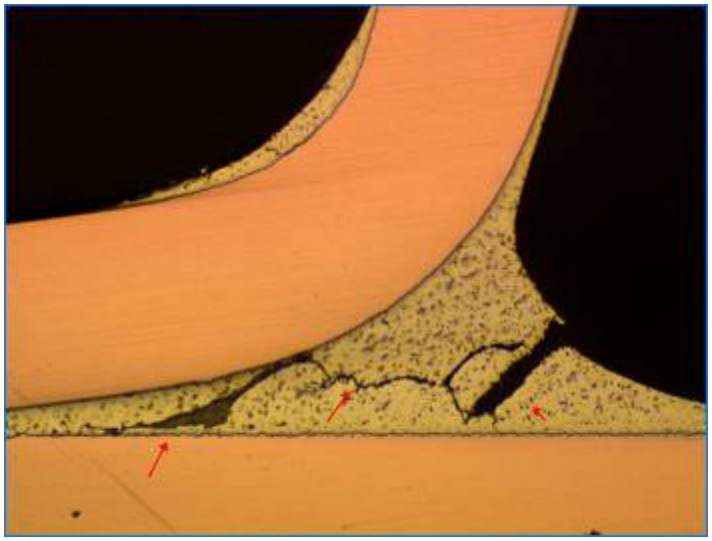

Figure 33: cross section, SN62, U31, left lead solder crack, 200x, a

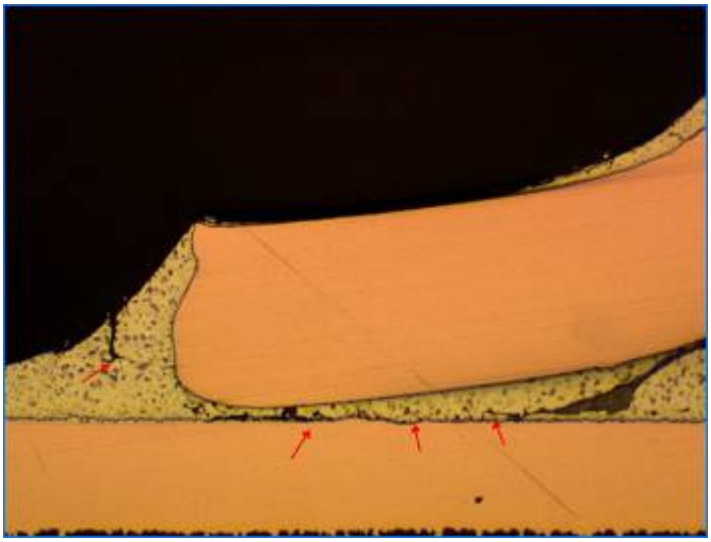

Figure 34: cross section, SN62, U31, left lead solder crack, 200x, b

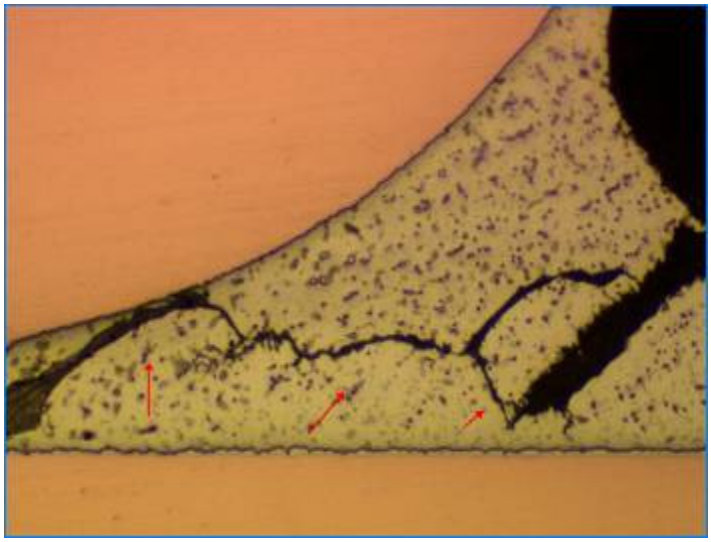

Figure 35: cross section, SN62, U31, left lead solder crack, 400x, a

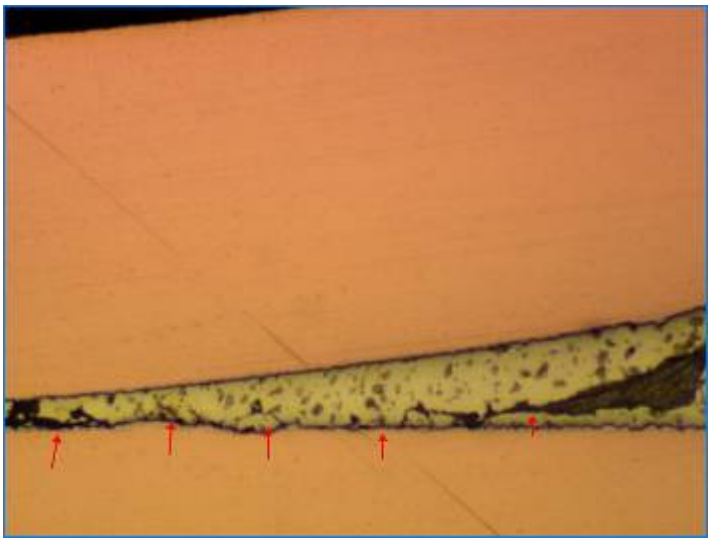

Figure 36: cross section, SN62, U31, left lead solder crack, 400x, b

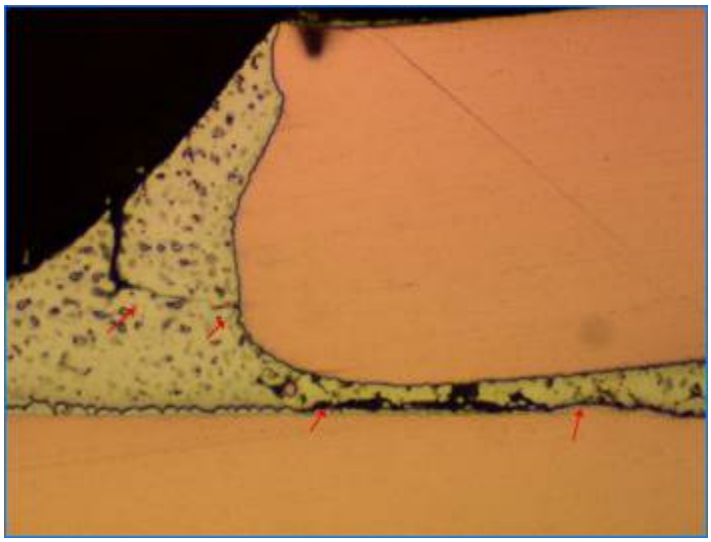

Figure 37: cross section, SN62, U31, left lead solder crack, 400x, c

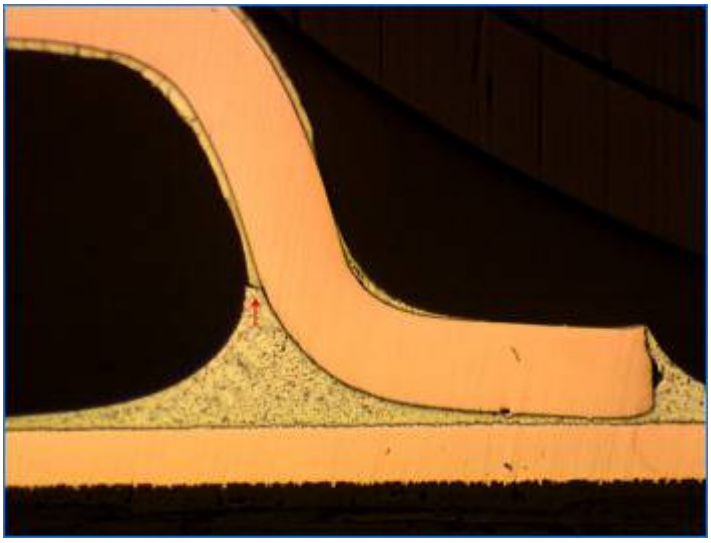

Figure 38: cross section, SN62, U31, right lead solder partial crack, 100x

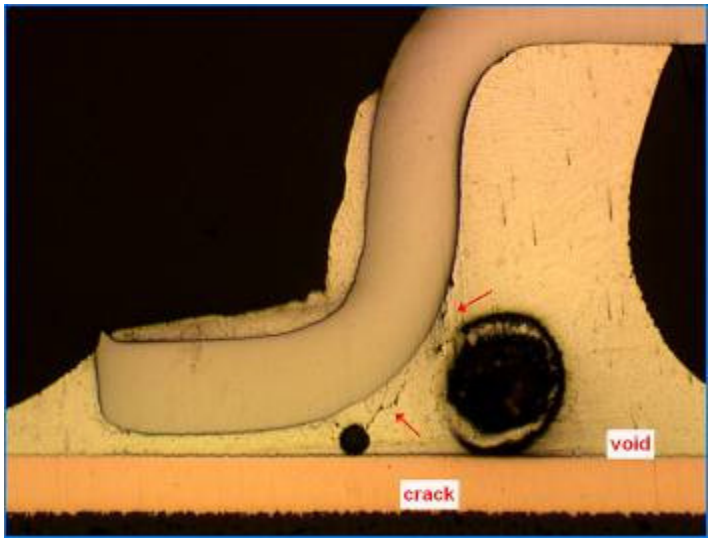

Figure 39: cross section, SN62, U61, left lead solder crack and voids, 100x

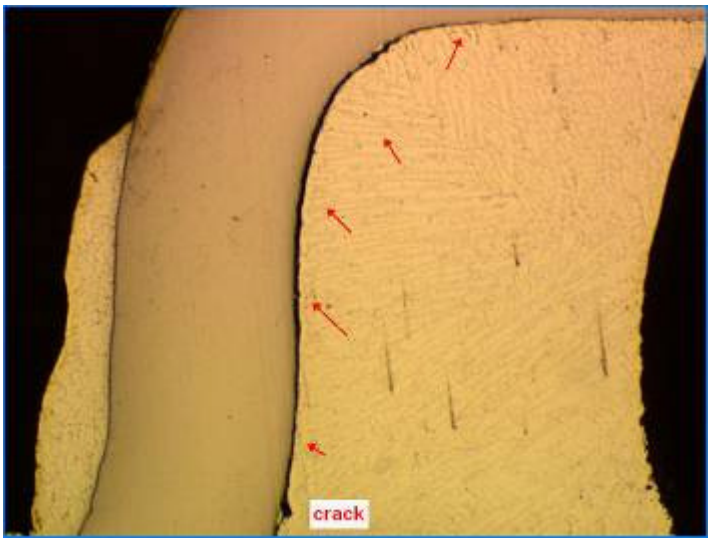

Figure 40: cross section, SN62, U61, left lead solder crack and voids, 200x b

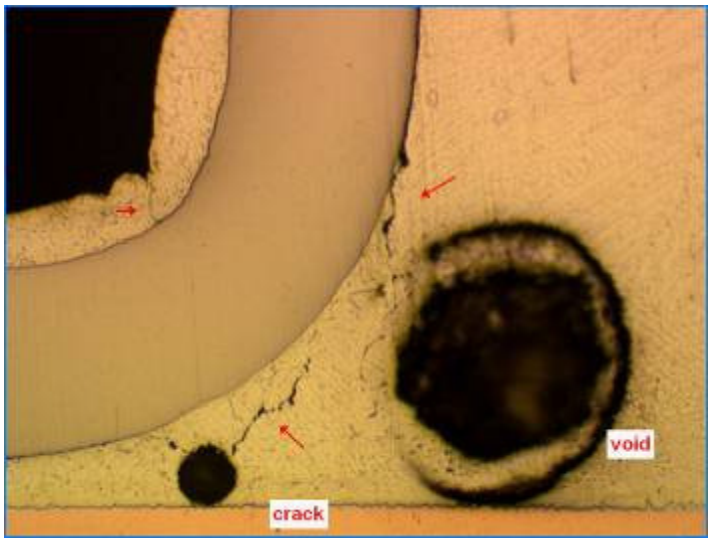

Figure 41: cross section, SN62, U61, left lead solder crack and voids, 200x

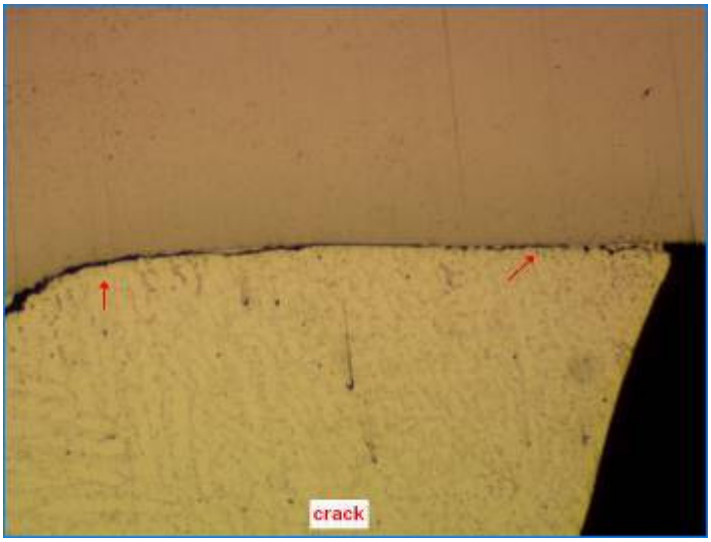

Figure 42: cross section, SN62, U61, left lead solder crack, 400x a

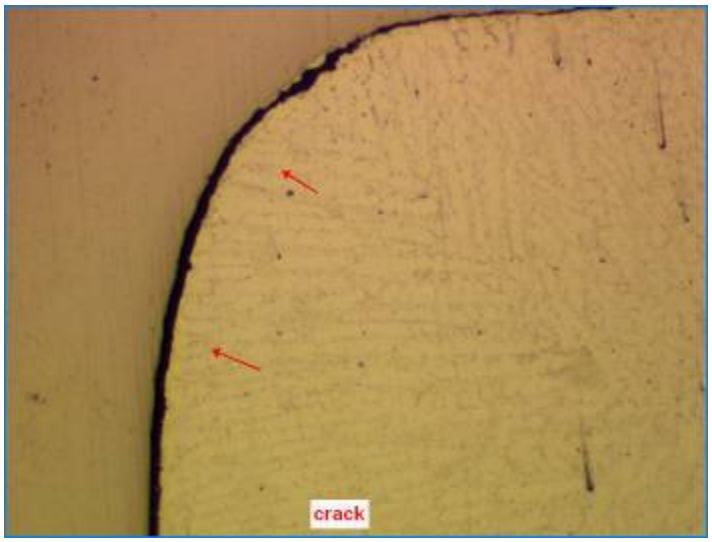

Figure 43: cross section, SN62, U61, left lead solder crack, 400x b

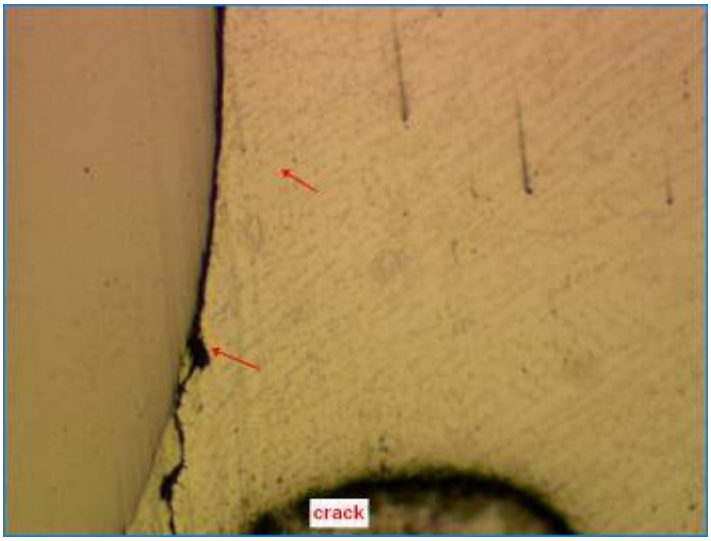

Figure 44: cross section, SN62, U61, left lead solder crack, 400x c

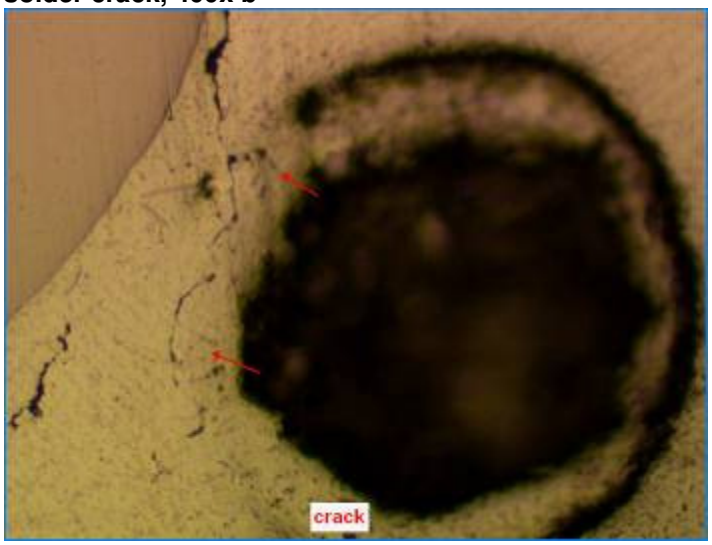

Figure 45: cross section, SN62, U61, left lead solder crack, 400x d

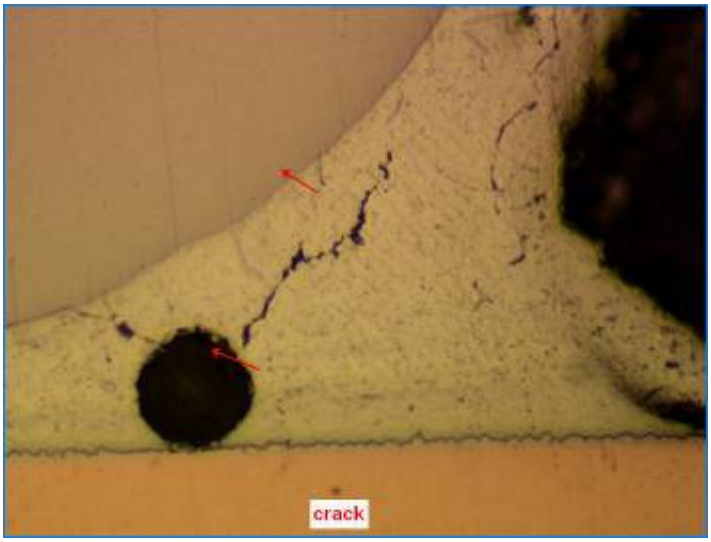

Figure 46: cross section, SN62, U61, left lead solder crack, 400x f

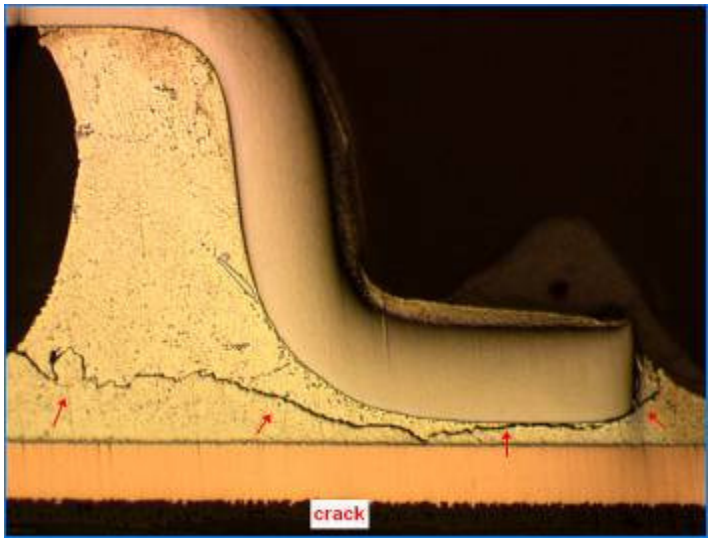

Figure 47: cross section, SN62, U61, right lead solder crack, 100x

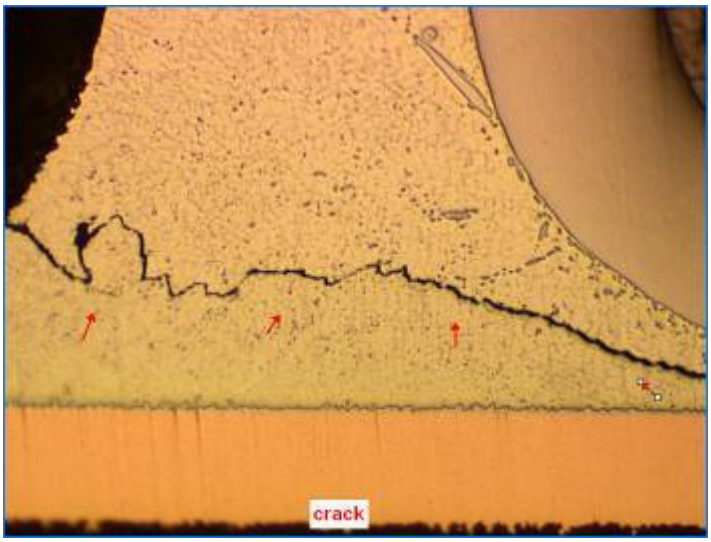

Figure 48: cross section, SN62, U61, right lead solder crack, 200x a

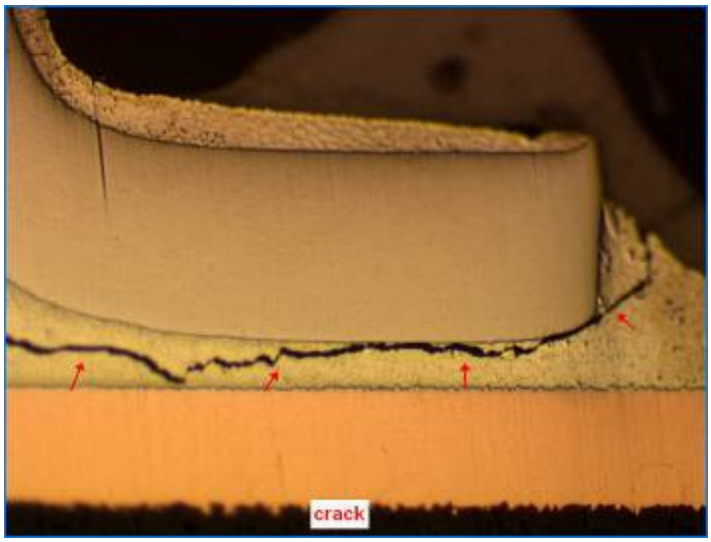

Figure 49: cross section, SN62, U61, right lead solder crack, 200x b

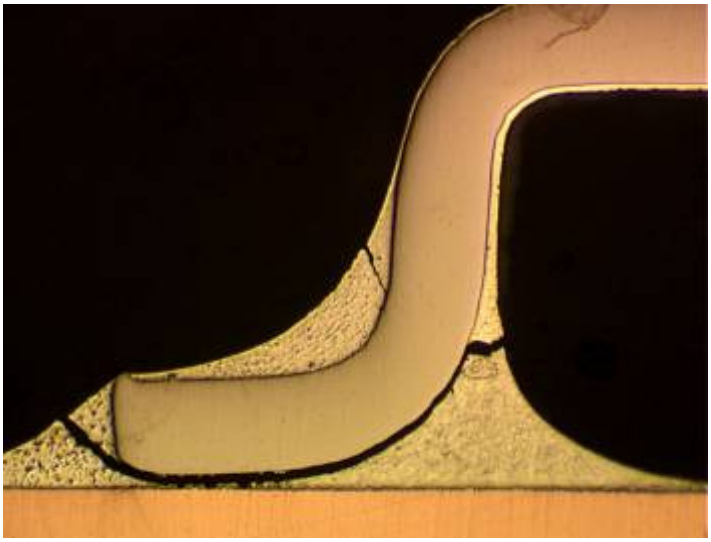

Figure 50: cross section, SN63, U16, left lead solder crack, 100xa

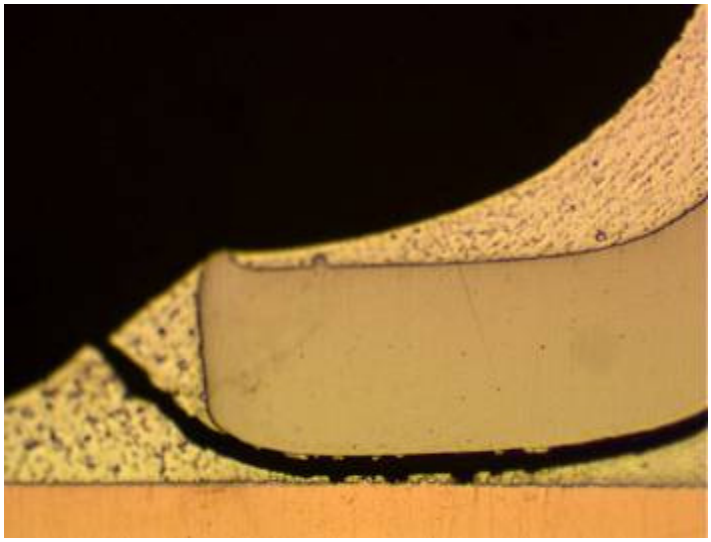

Figure 51: cross section, SN63, U16, left lead solder crack, 200xa

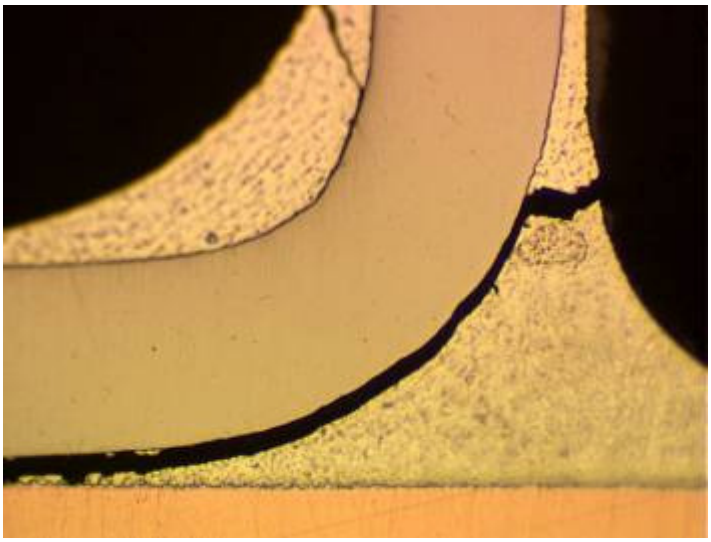

Figure 52: cross section, SN63, U16, left lead solder crack, 200xb

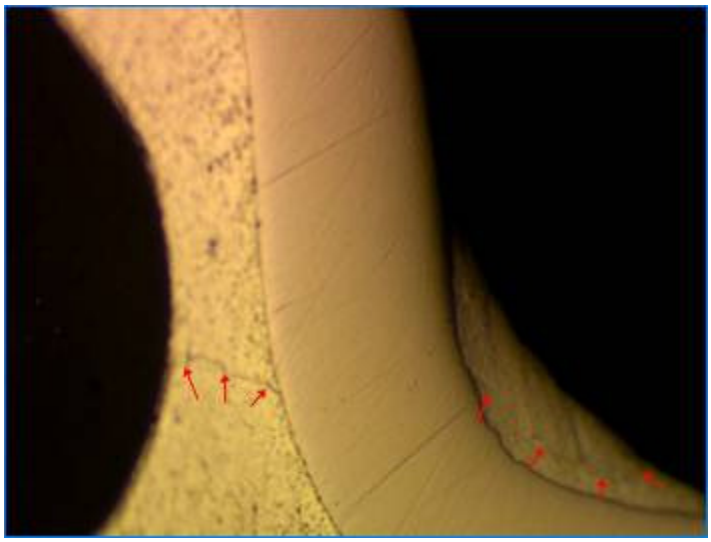

Figure 53: cross section, SN63, U16, right lead solder crack, 200x

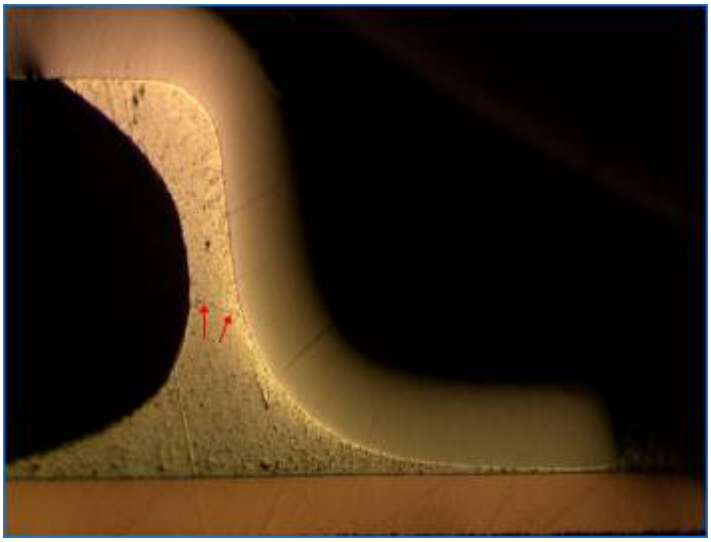

Figure 54: cross section, SN63, U16,right lead solder crack, 100x

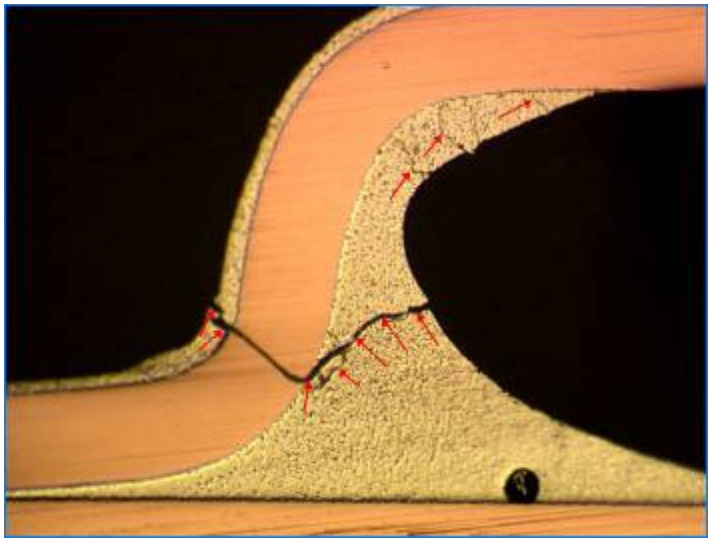

Figure 55: cross section, SN63, U20, left lead and solder crack and void, 100x

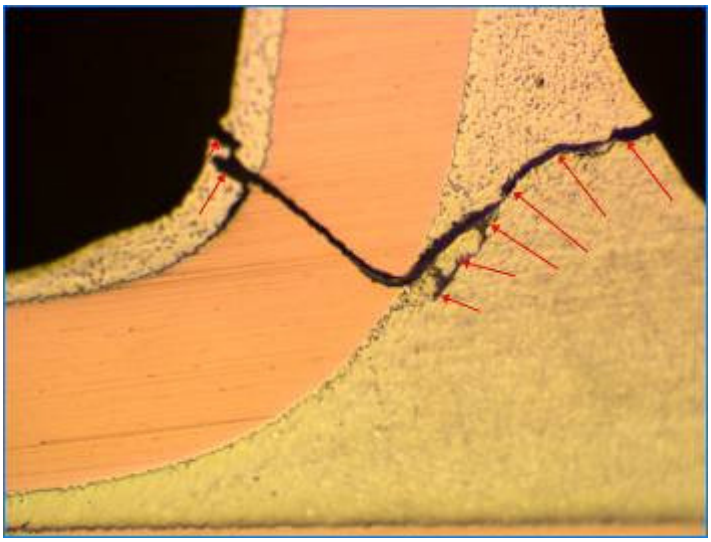

Figure 56: cross section, SN63, U20, left lead and solder crack and void, 200xa

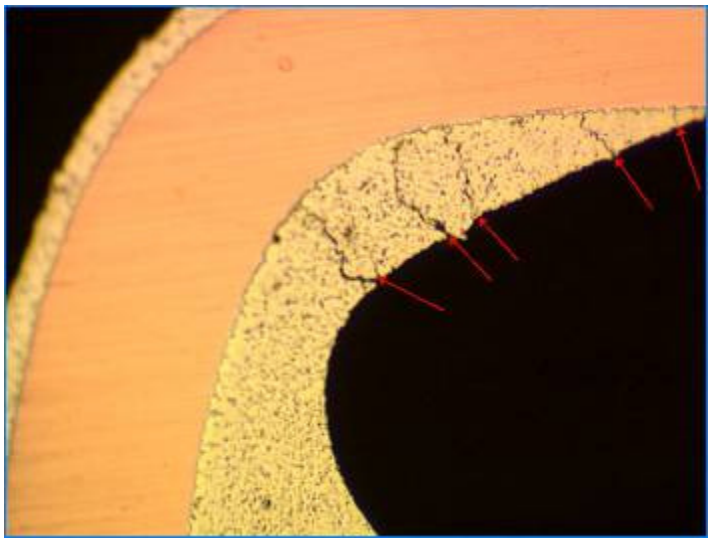

Figure 57: cross section, SN63, U20, left lead and solder crack and void, 200xb

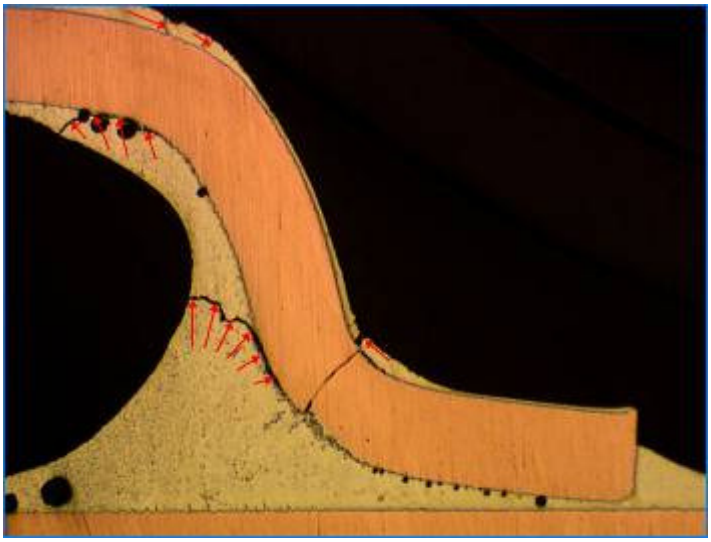

Figure 58: cross section, SN63, U20, right lead and solder crack and voids, 100x

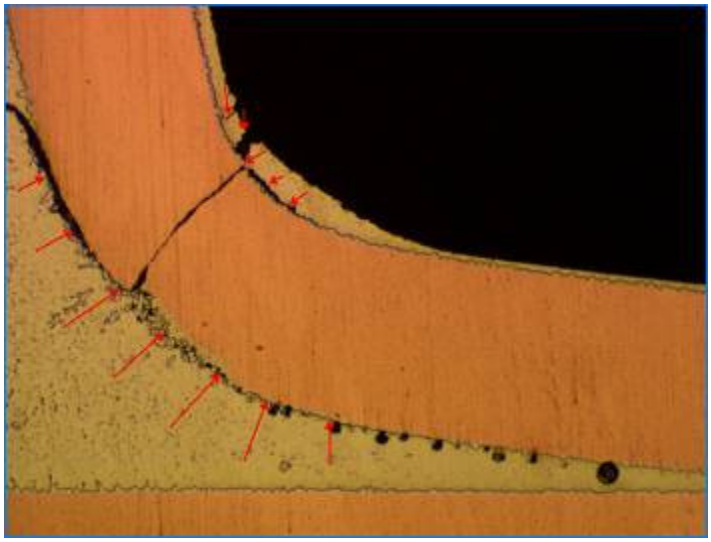

Figure 59: cross section, SN63, U20, right lead and solder crack and voids, 200xa

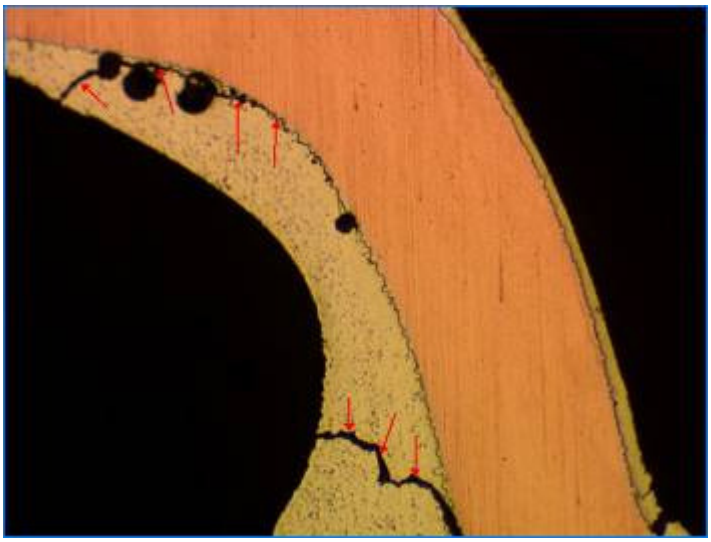

Figure 60: cross section, SN63, U20, right lead and solder crack and voids, 200xb

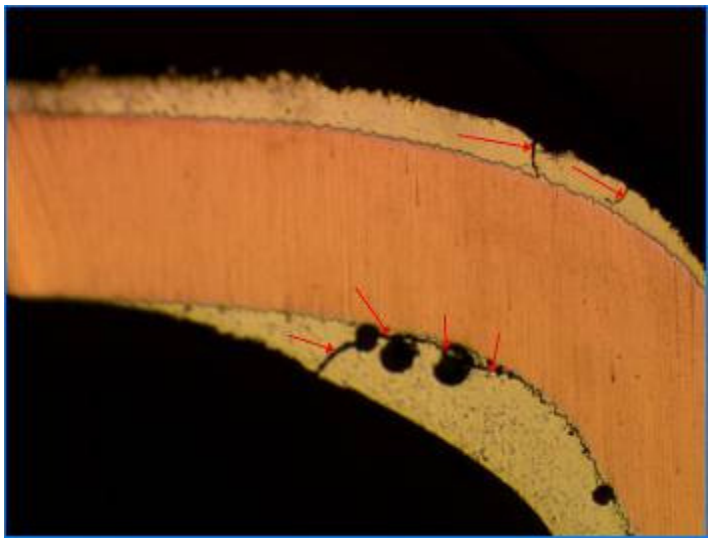

Figure 61: cross section, SN63, U20, right lead and solder crack and voids, 200xc

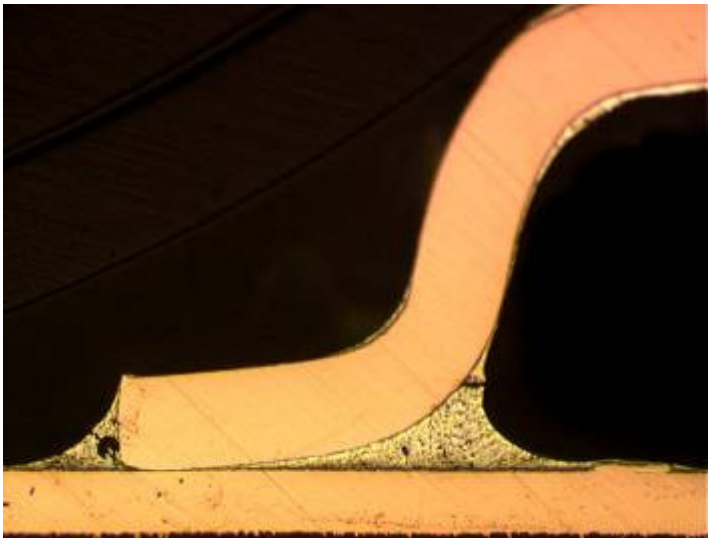

Figure 62: cross section, SN63, U31, left lead solder crack, 100x

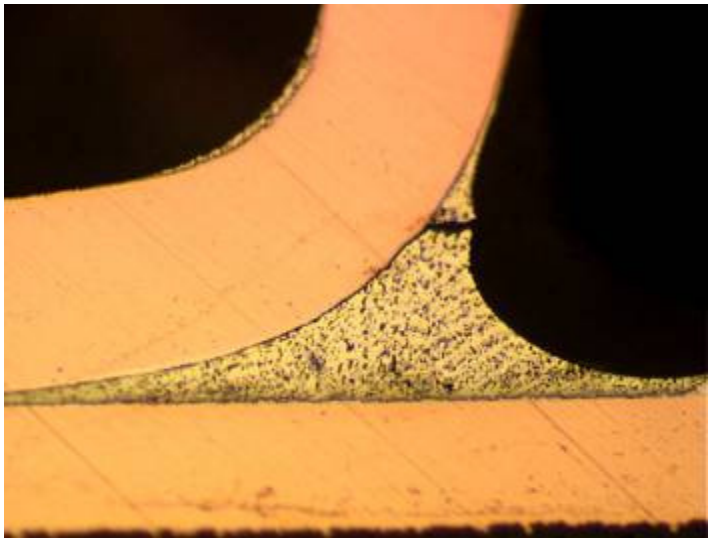

Figure 63: cross section, SN63, U31, left lead solder crack, 200xb

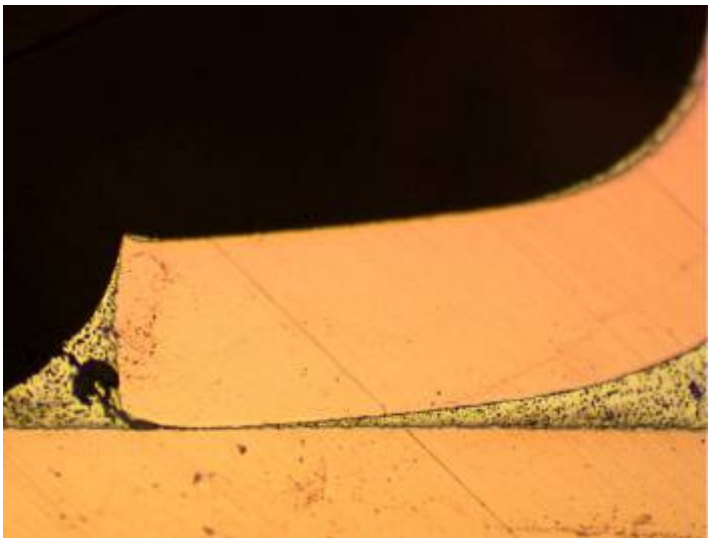

Figure 64: cross section, SN63, U31,left lead solder crack, 200xa

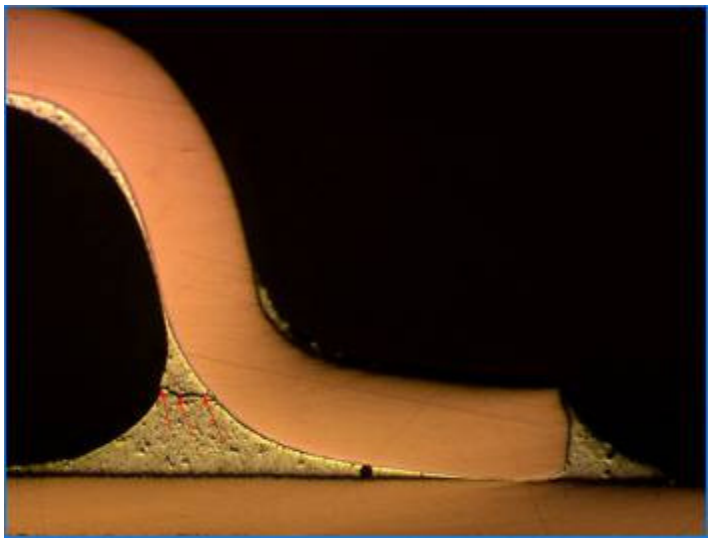

Figure 65: cross section, SN63, U31,right lead solder crack, 100x

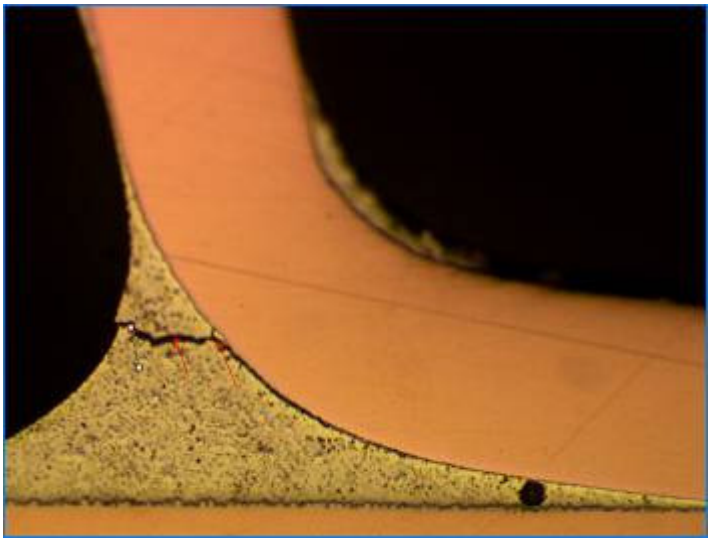

Figure 66: cross section, SN63, U31, right lead solder crack, 200x

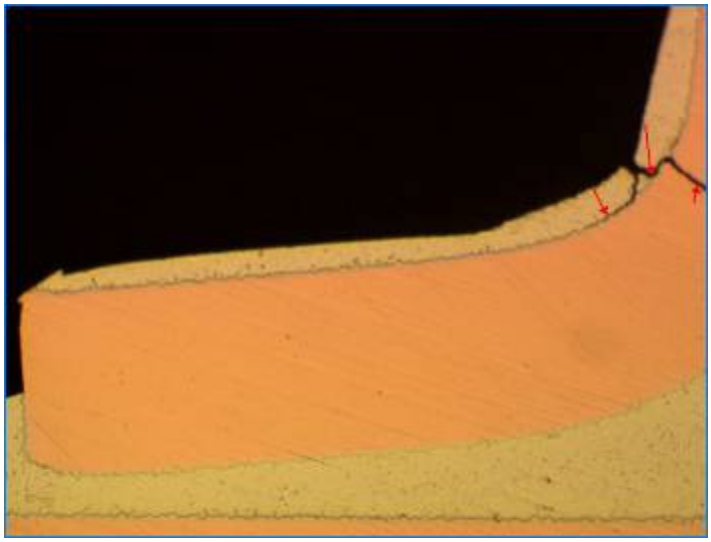

Figure 67: cross section, SN63, U41, left lead crack, 200xa

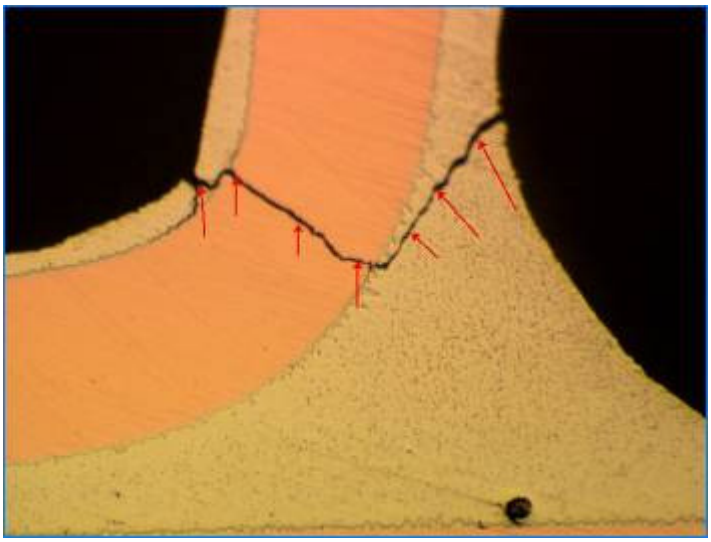

Figure 68: cross section, SN63, U41, left lead crack, 200xb

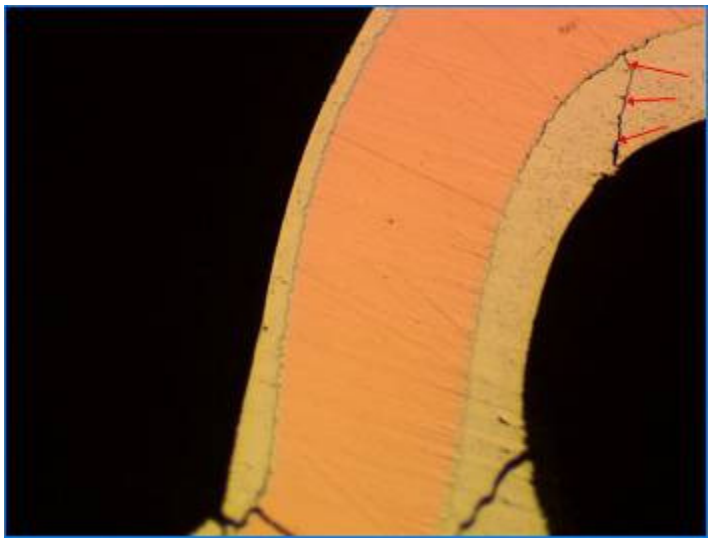

Figure 69: cross section, SN63, U41, left lead crack, 200xc

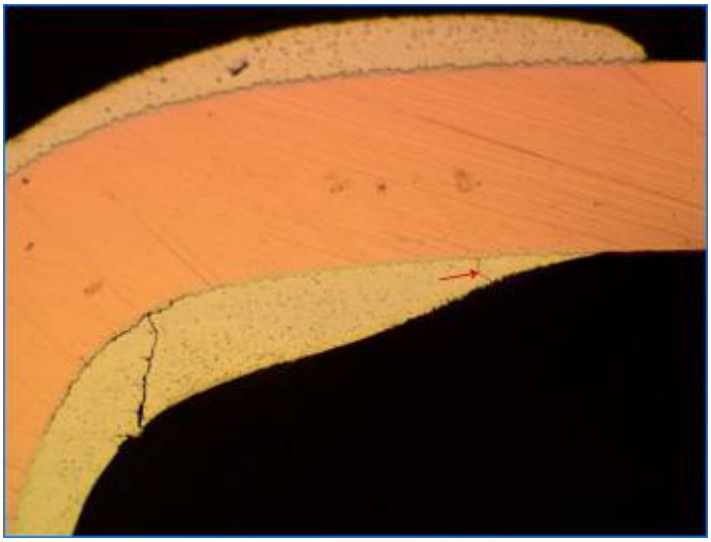

Figure 70: cross section, SN63, U41, left lead crack, 200xd

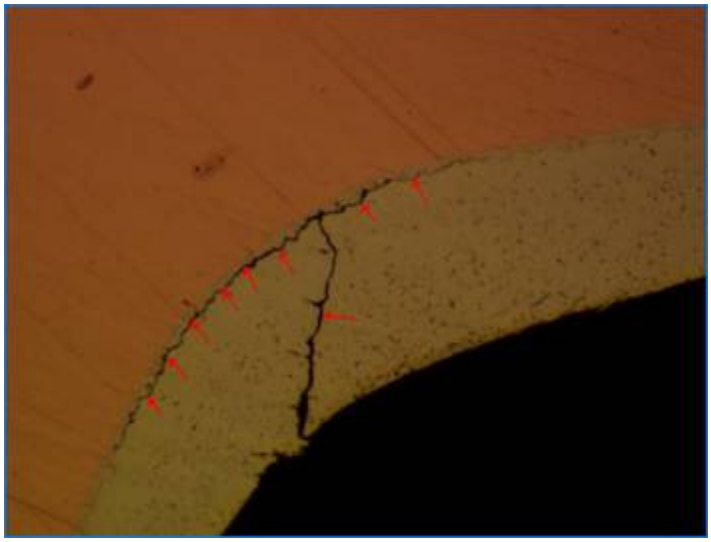

Figure 71: cross section, SN63, U41, left lead crack, 400x

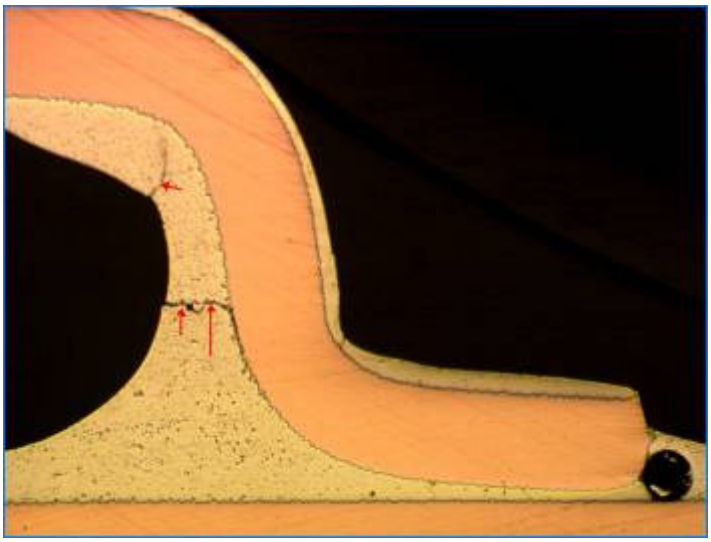

Figure 72: cross section, SN63, U41, right lead solder crack, 100x

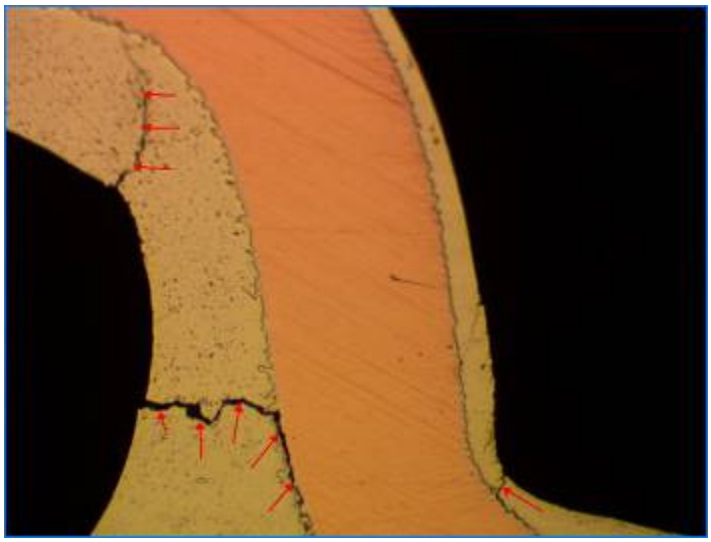

Figure 73: cross section, SN63, U41, right lead solder crack, 200x

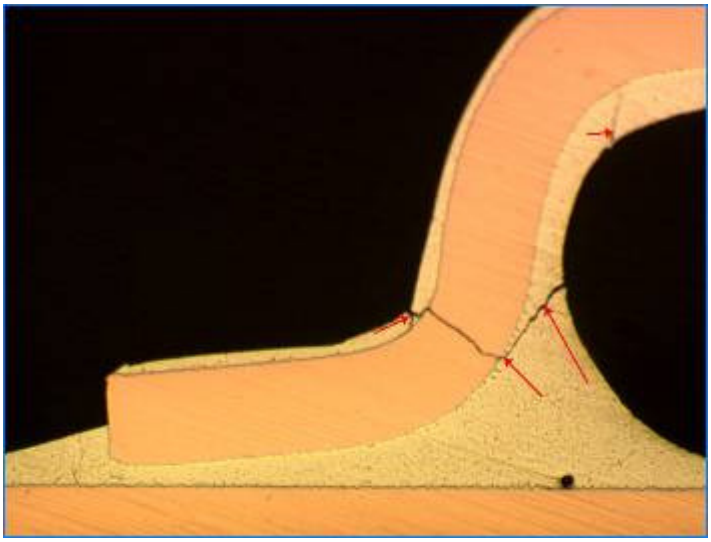

Figure 74: cross section, SN63, U41,left lead crack, 100x

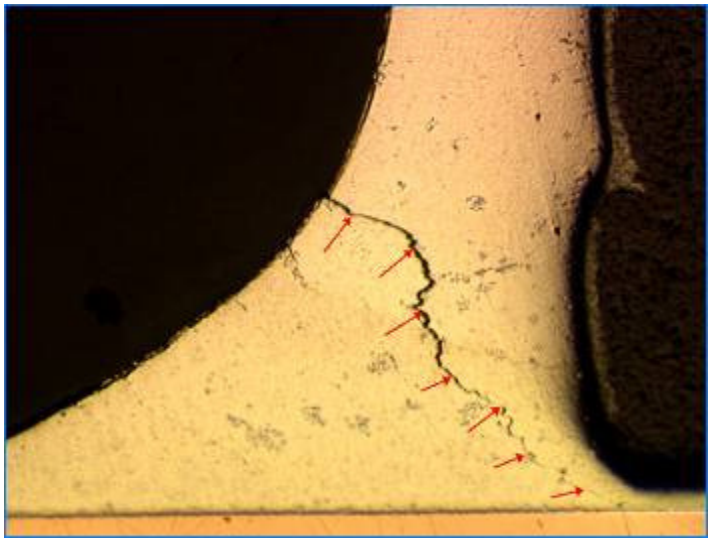

Figure 75: cross section, SN63, U52, left pad solder crack, 100x

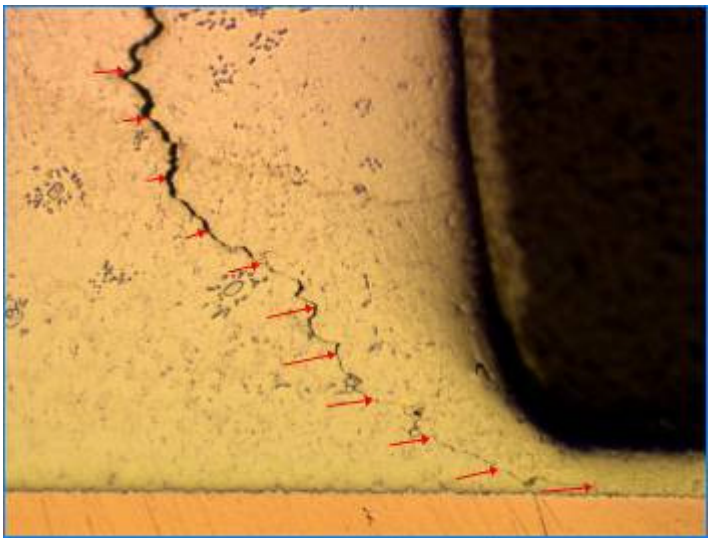

Figure 76: cross section, SN63, U52, left pad solder crack, 200xa

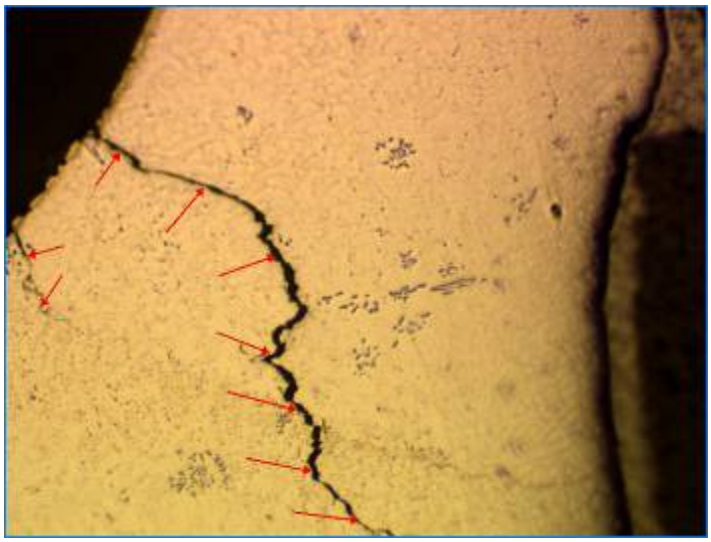

Figure 77: cross section, SN63, U52, left pad solder crack, 200xb

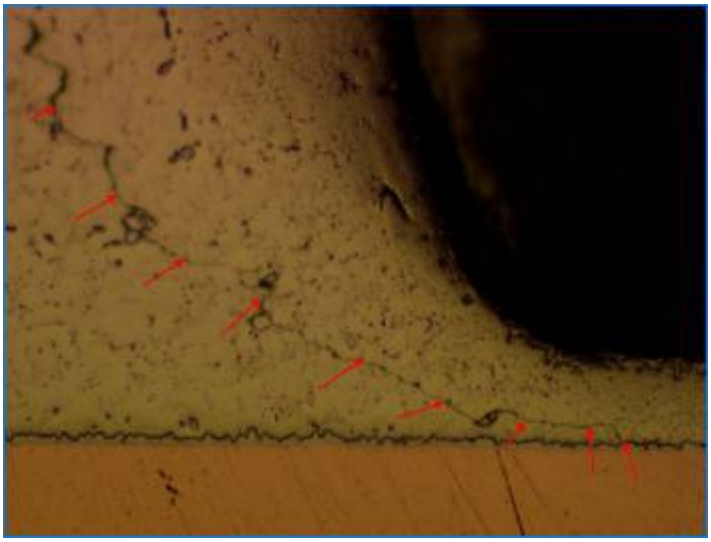

Figure 78: cross section, SN63, U52, left pad solder crack, 400x

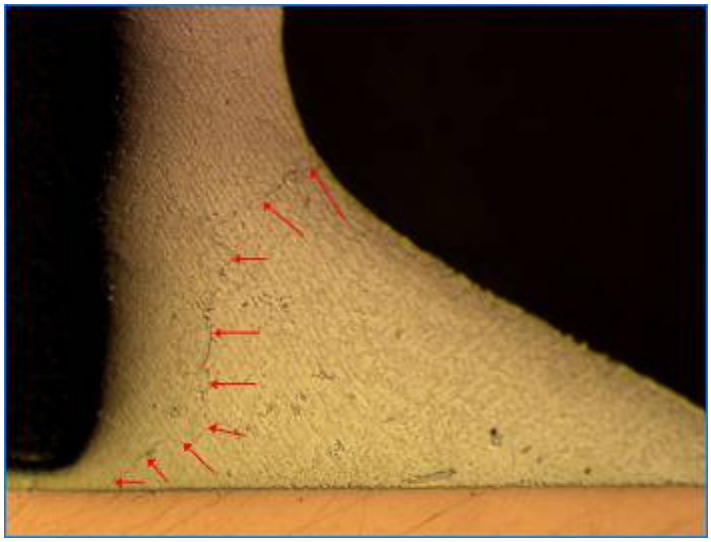

Figure 79: cross section, SN63, U52, right pad solder crack, 100x

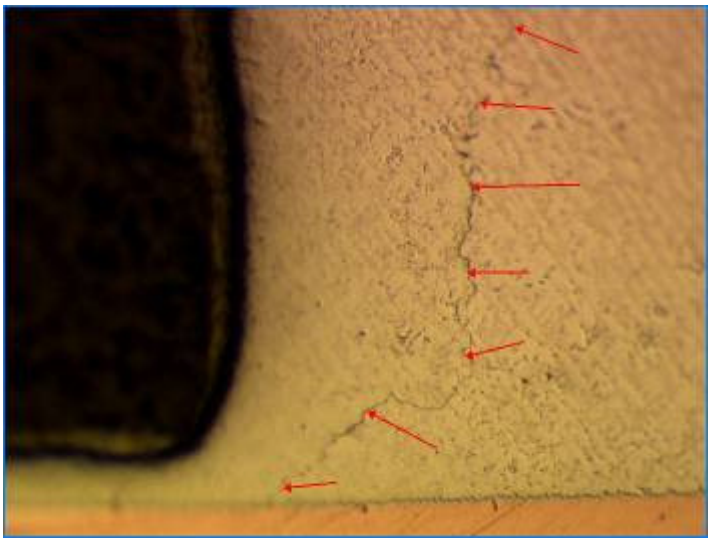

Figure 80: cross section, SN63, U52, right pad solder crack, 200xa

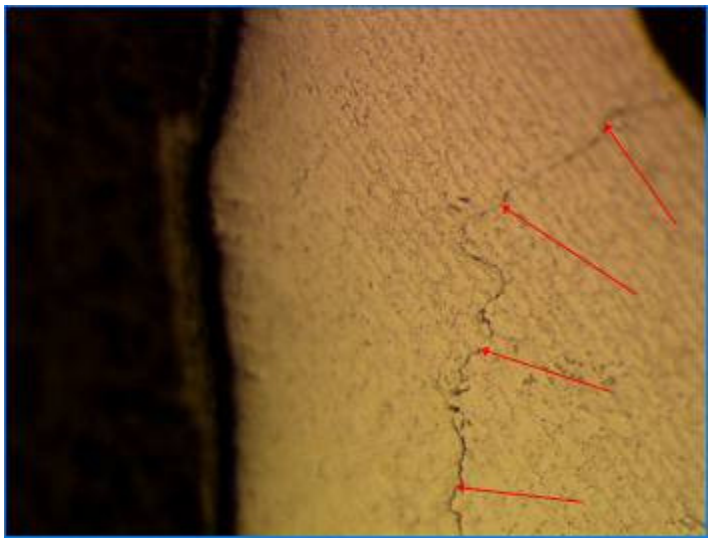

Figure 81: cross section, SN63, U52, right pad solder crack, 200xb

Figure 82: cross section, SN63, U54, left pad solder crack, 100x

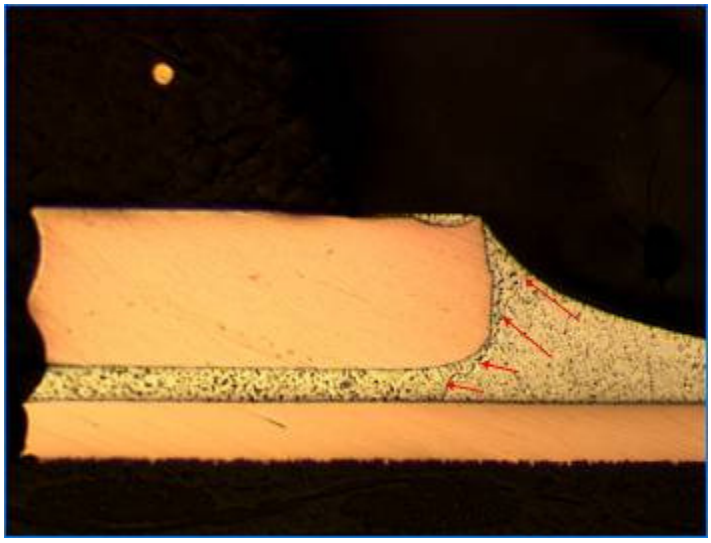

Figure 83: cross section, SN63, U54, righ pad solder crack, 100x

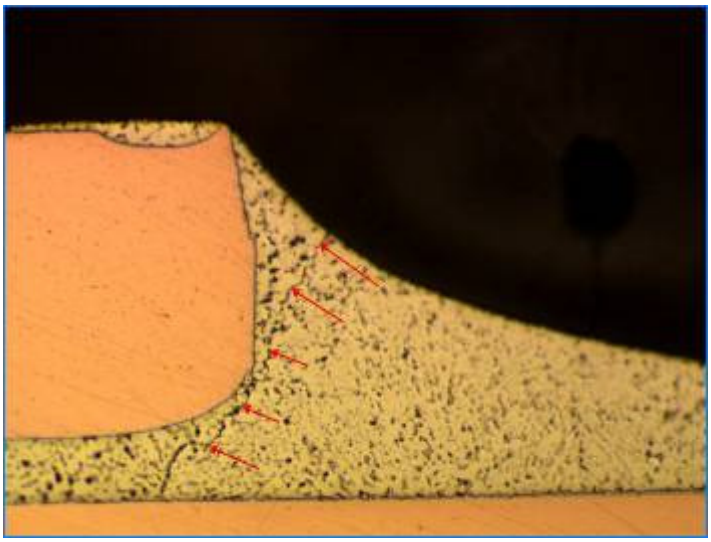

Figure 84: cross section, SN63, U54, right pad solder crack, 200x

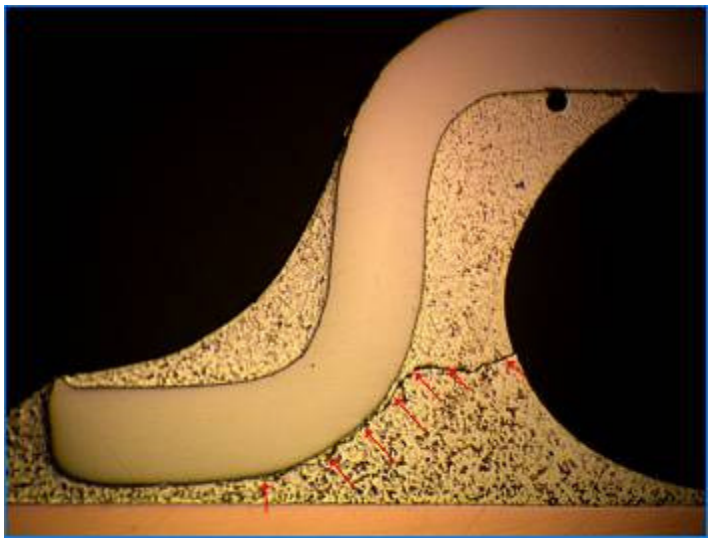

Figure 85: cross section, SN63, U61, left lead solder crack, 100x

Figure 86: cross section, SN63, U61, left lead solder crack, 200xa

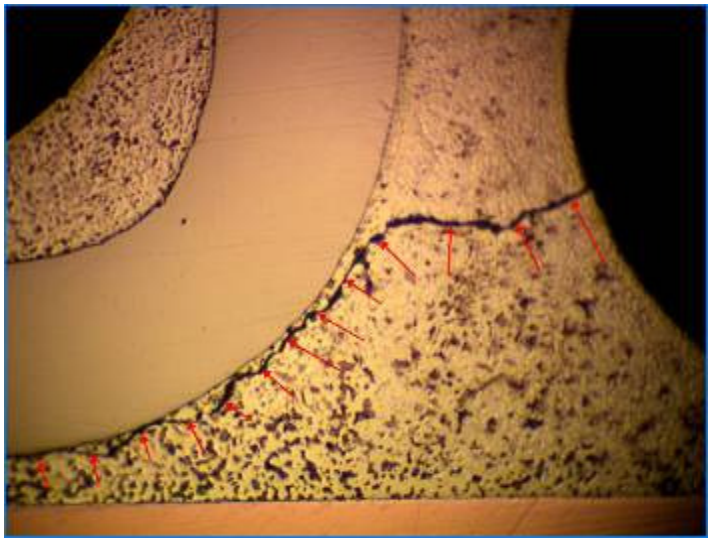

Figure 87: cross section, SN63, U61, left lead solder crack, 200xb

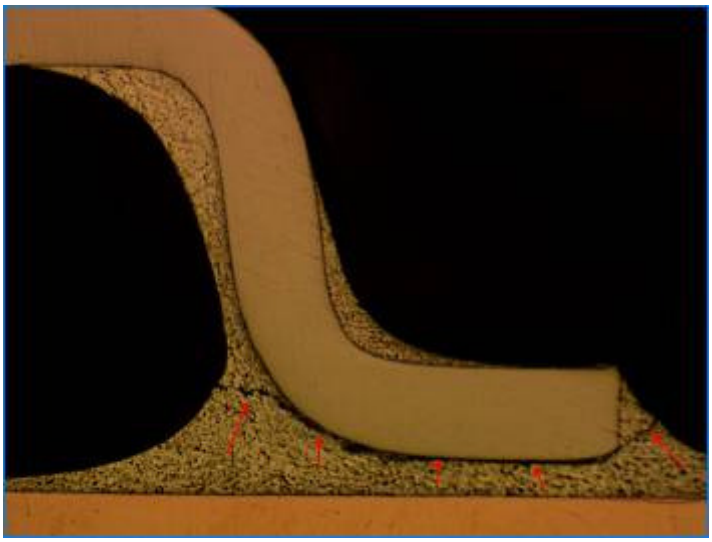

Figure 88: cross section, SN63, U61, right lead solder crack, 100x

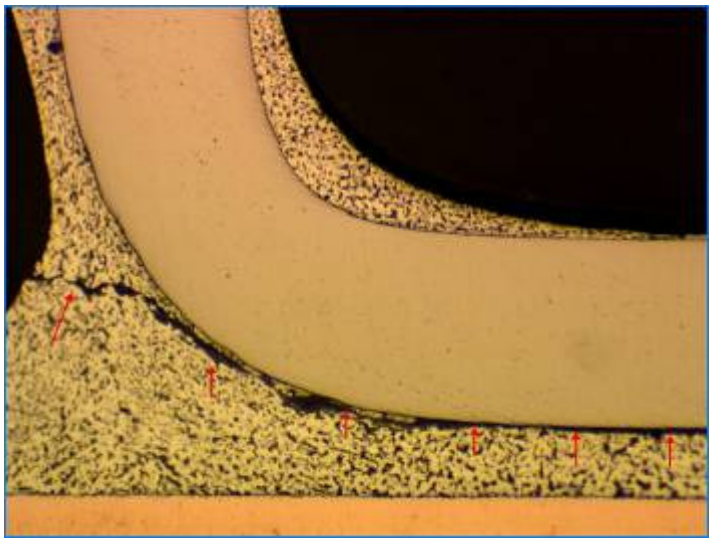

Figure 89: cross section, SN63, U61, right lead solder crack, 200xa

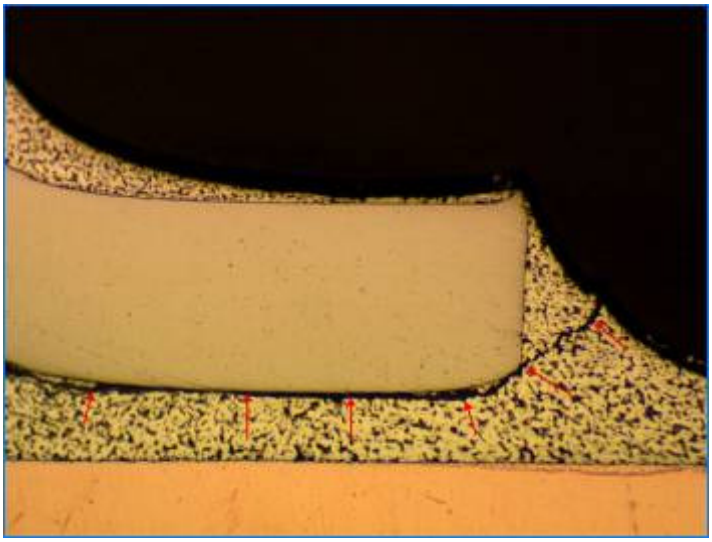

Figure 90: cross section, SN63, U61, right lead solder crack, 200xb

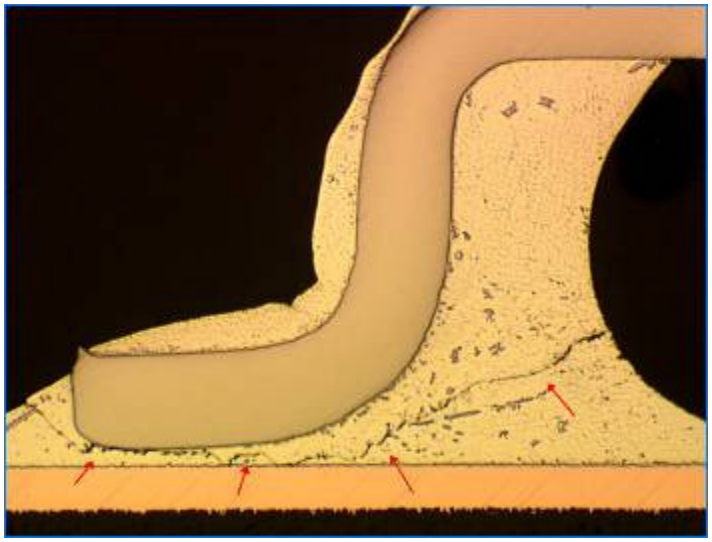

Figure 91: cross section, SN64, U62, left lead solder crack, 100x

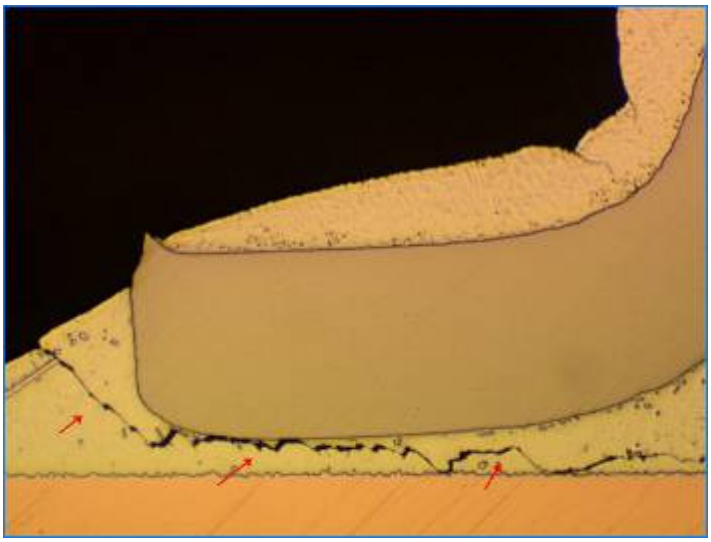

Figure 92: cross section, SN64, U62, left lead solder crack, 200xa

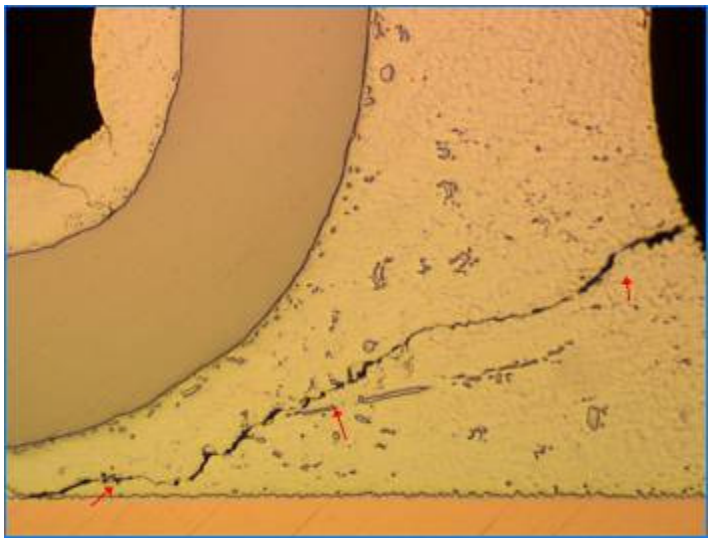

Figure 93: cross section, SN64, U62, left lead solder crack, 200xb

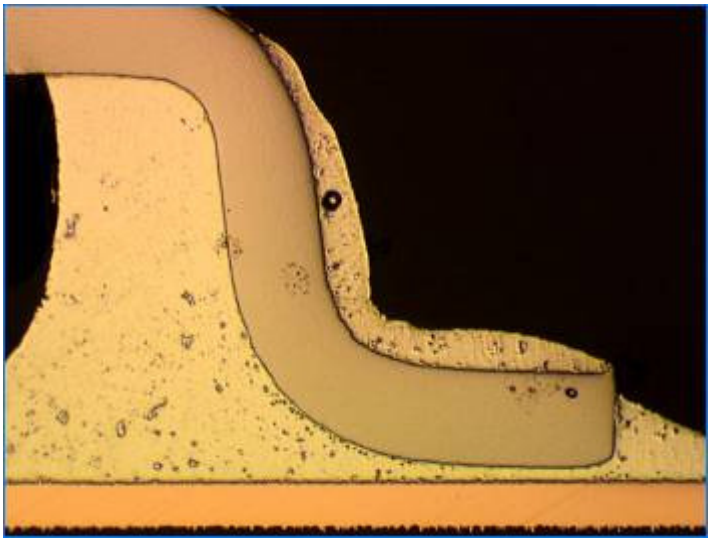

Figure 94: cross section, SN64, U62, right lead, 100x

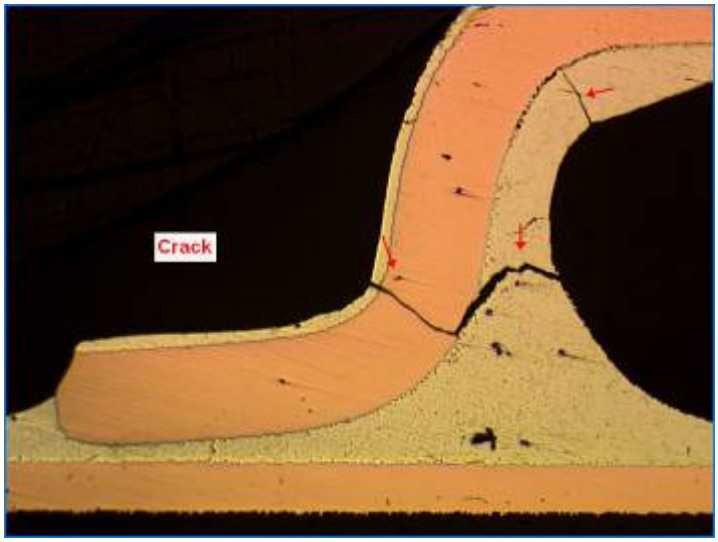

Figure 95: cross section, SN65, U20, left lead and solder crack, 100x

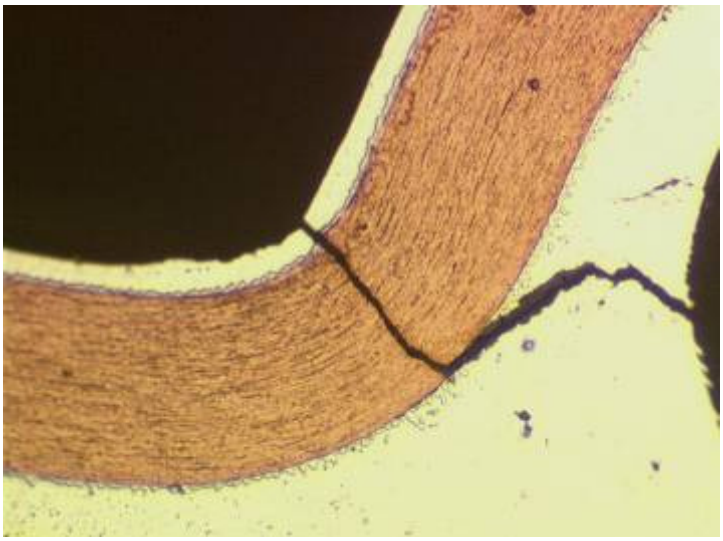

Figure 96: cross section, SN65, U20, left lead, 200x, after etching

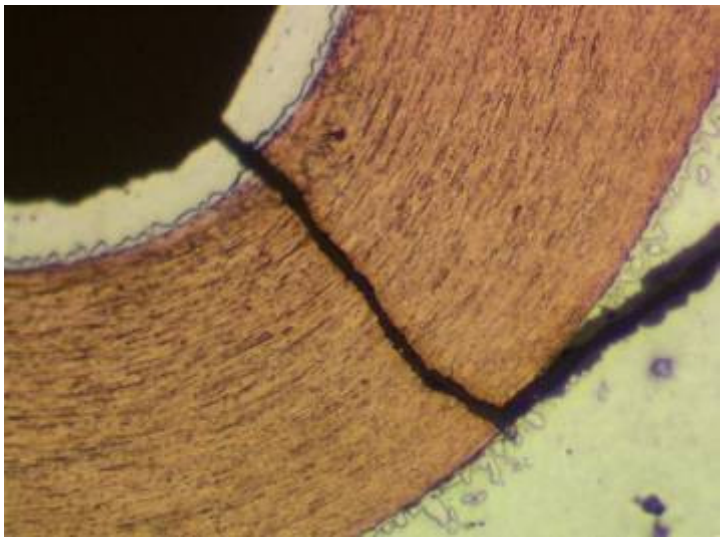

Figure 97: cross section, SN65, U20, left lead, 400x, after etching

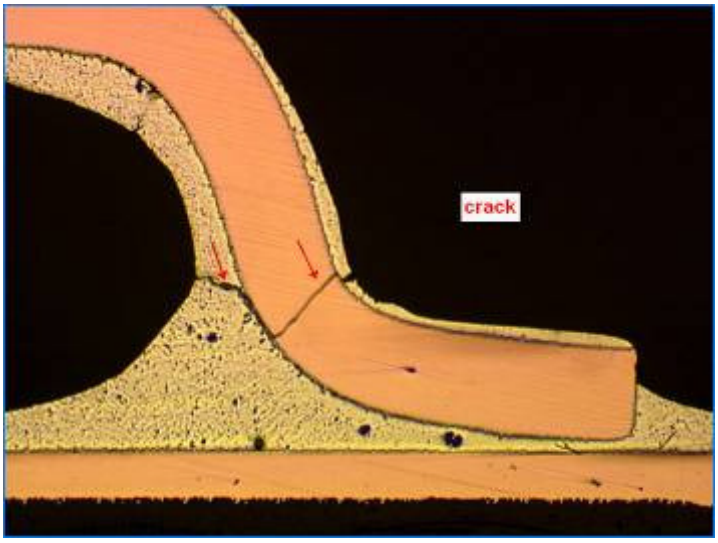

Figure 98: cross section, SN65, U20, right lead and solder crack, 100x

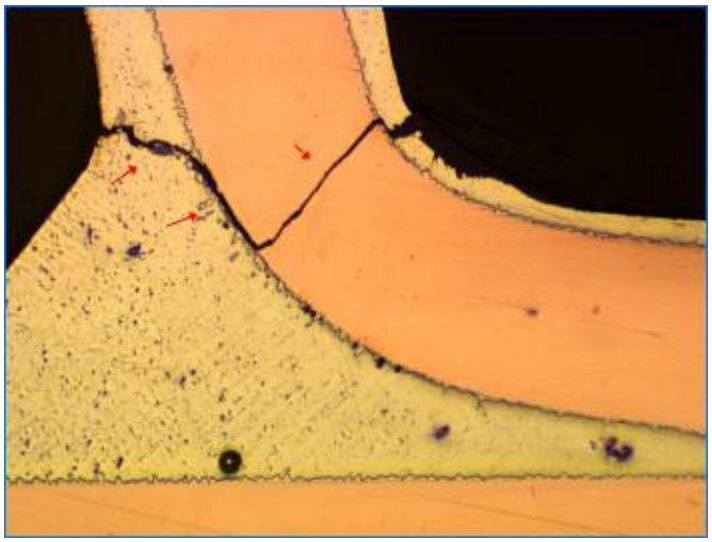

Figure 99: cross section, SN65, U20, right lead and solder crack, 200x

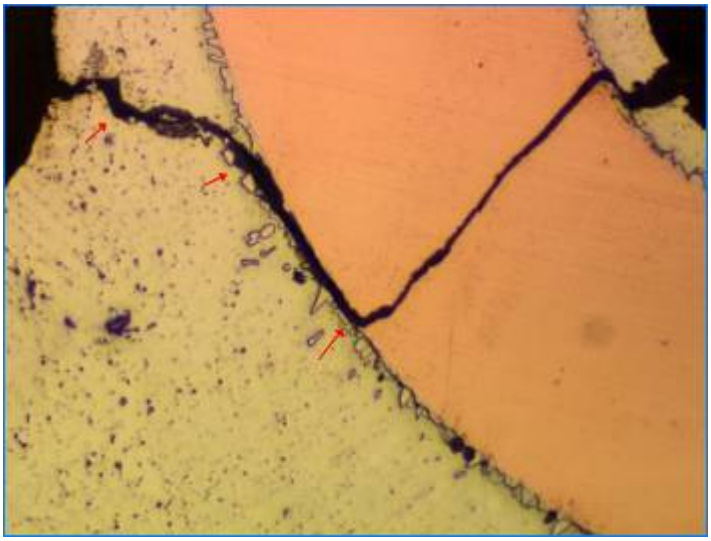

Figure 100: cross section, SN65, U20, right lead and solder crack, 400x

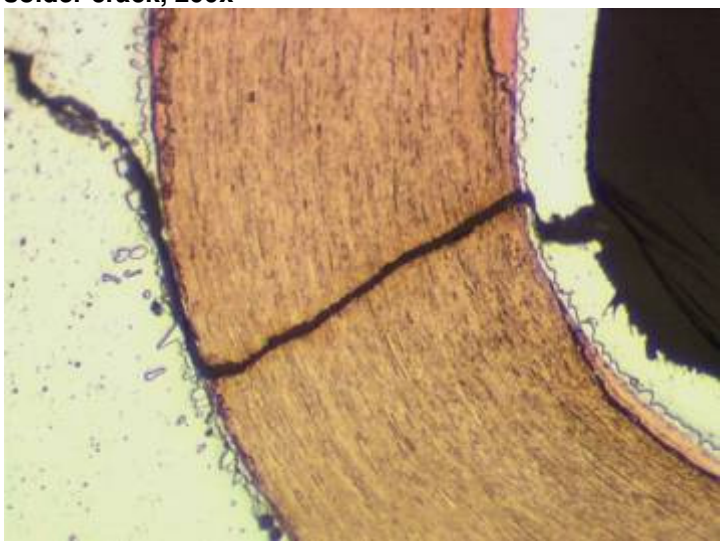

Figure 101: cross section, SN65, U20, right lead, after etching, 400x

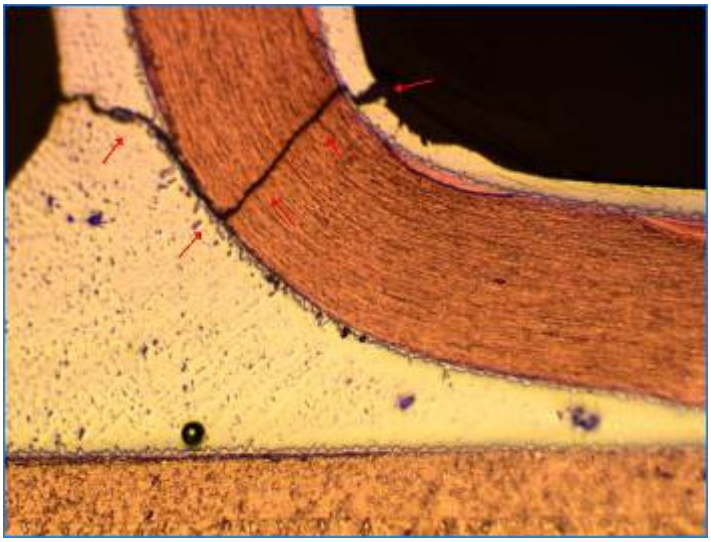

Figure 102: cross section, SN65, U20, right lead, after etching, 200x

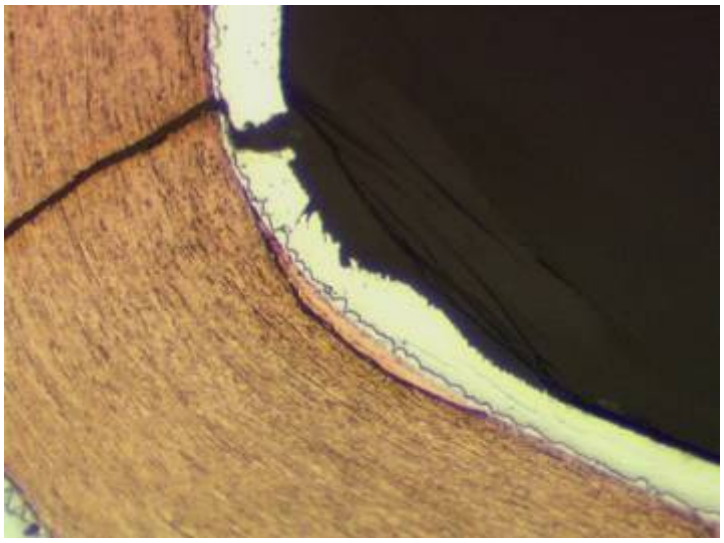

Figure 103: cross section, SN65, U20, right lead2, after etching, 400x

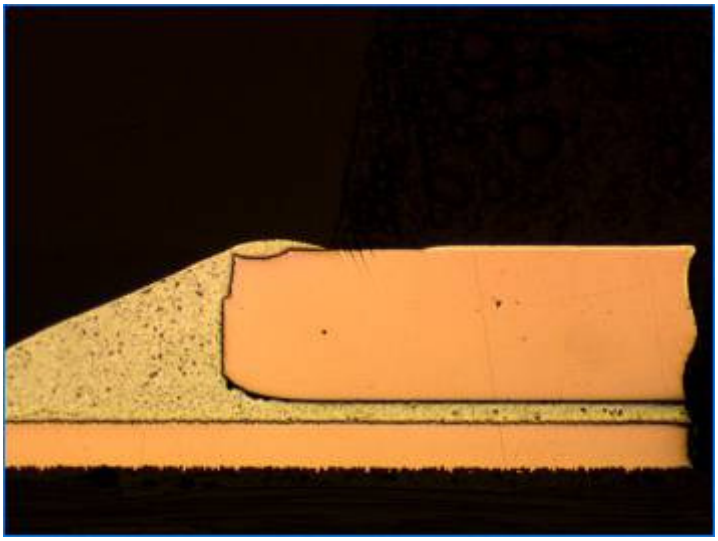

Figure 104: cross section, SN65, U28, left lead , 100x

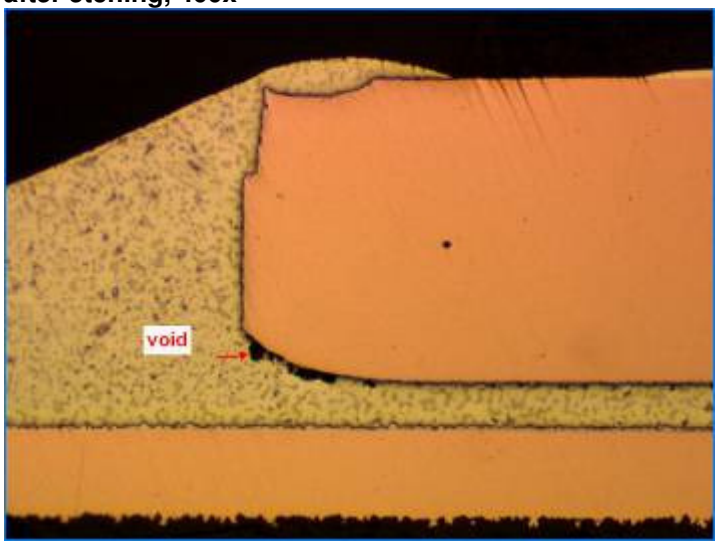

Figure 105: cross section, SN65, U28, left lead , void, 200x

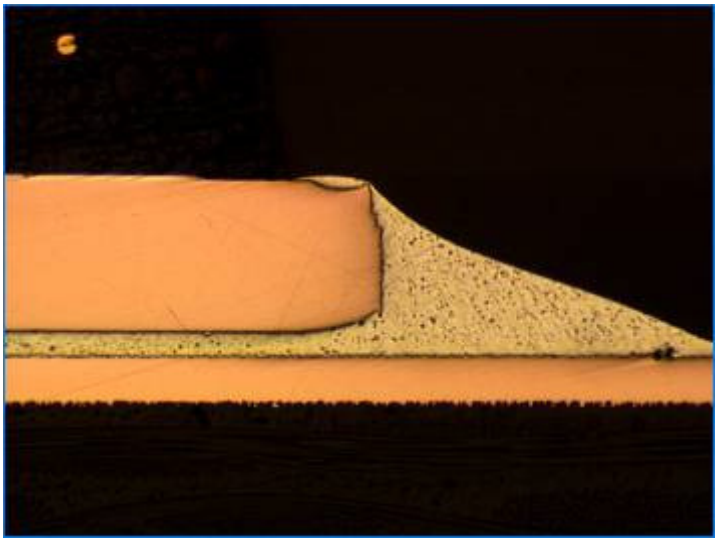

Figure 106: cross section, SN65, U28, right lead , 100x

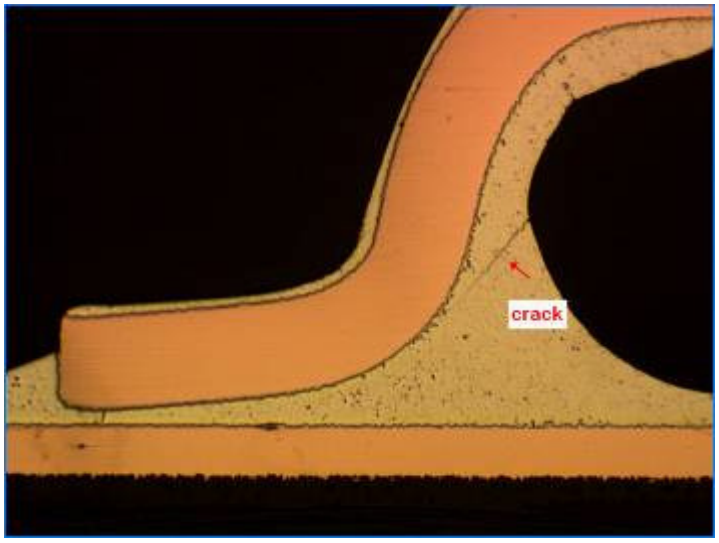

Figure 107: cross section, SN65, U41, left lead, partial solder crack, 100x

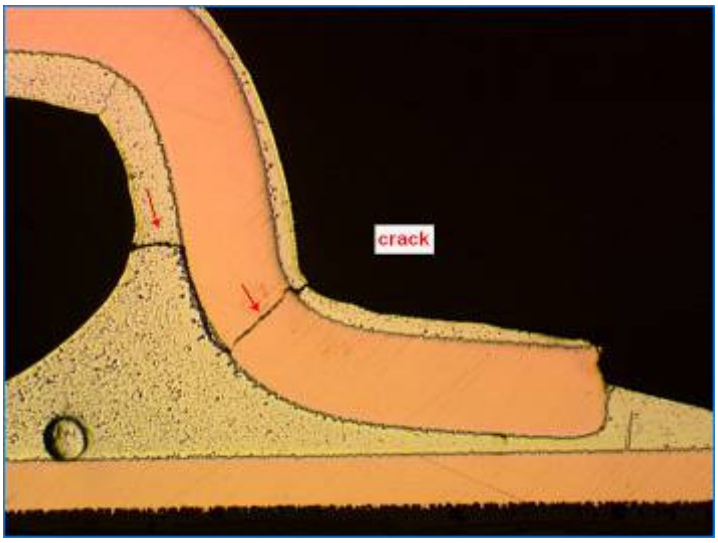

Figure 108: cross section, SN65, U41, right lead and solder crack, 100x

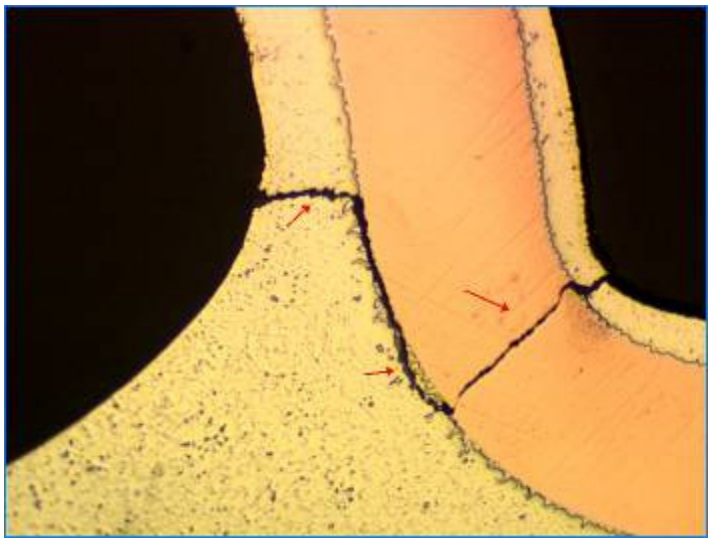

Figure 109: cross section, SN65, U41, right lead and solder crack, 200x

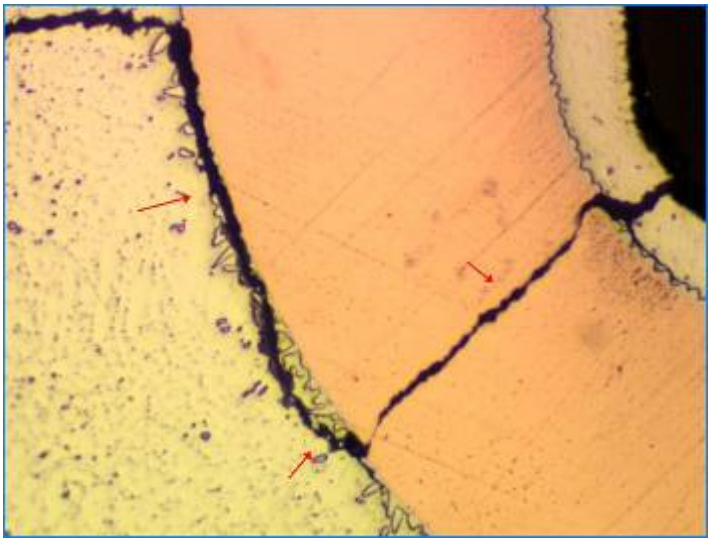

Figure 110: cross section, SN65, U41, right lead and solder crack, 400x

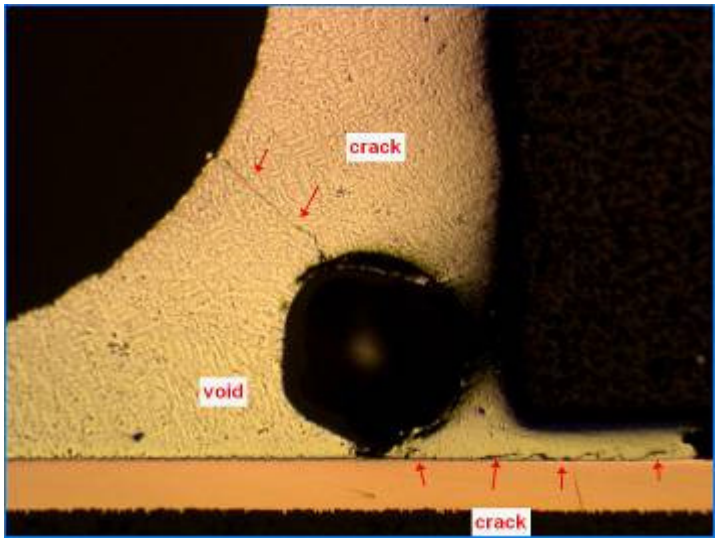

Figure 111: cross section, SN65, U52, left lead solder crack and void, 100x

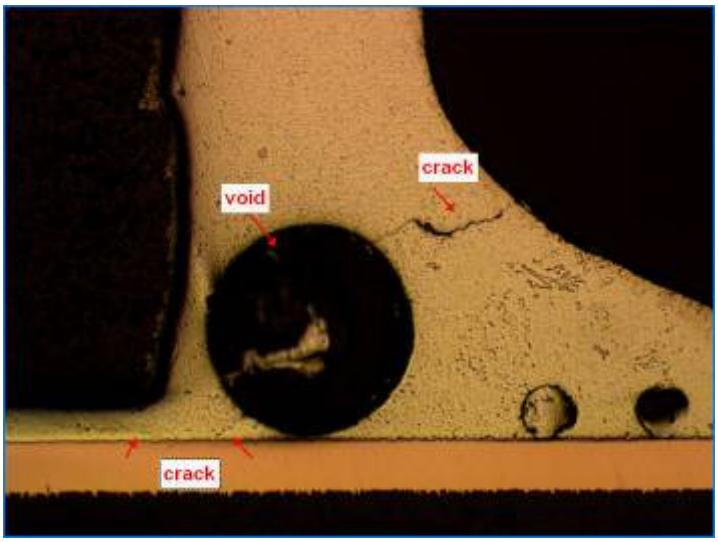

Figure 112: cross section, SN65, U52, right lead solder crack and void, 100x

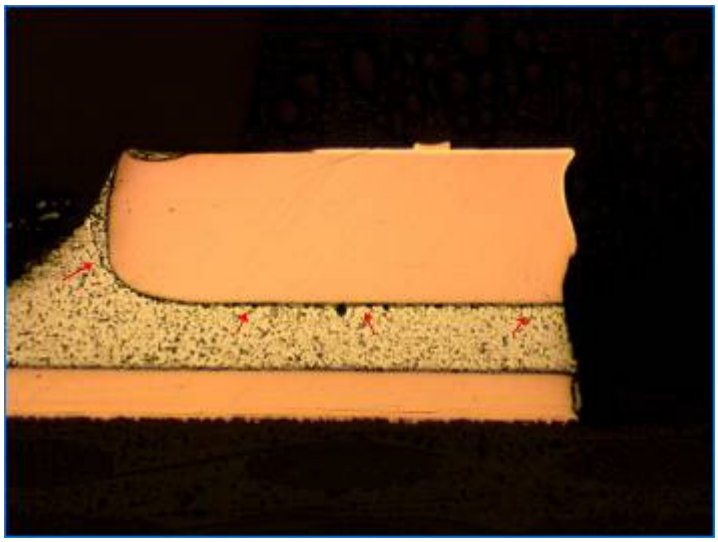

Figure 113: cross section, SN65, U54, left lead solder crack, 100x

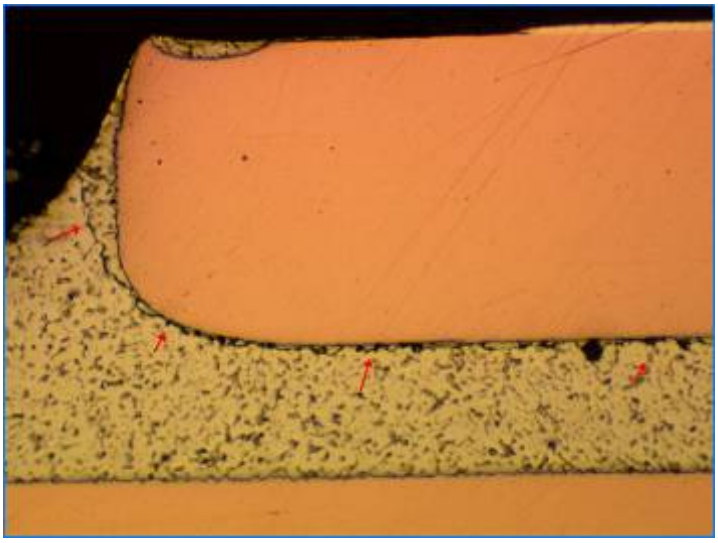

Figure 114: cross section, SN65, U54, left lead solder crack, 200x a

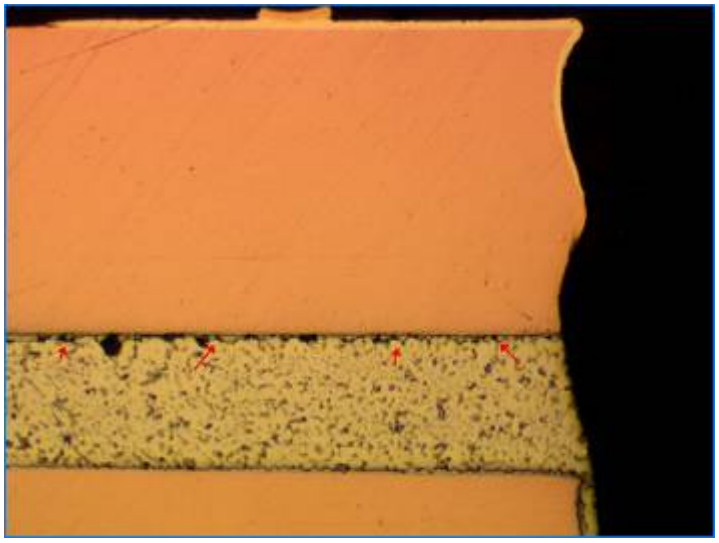

Figure 115: cross section, SN65, U54, left lead solder crack, 200x b

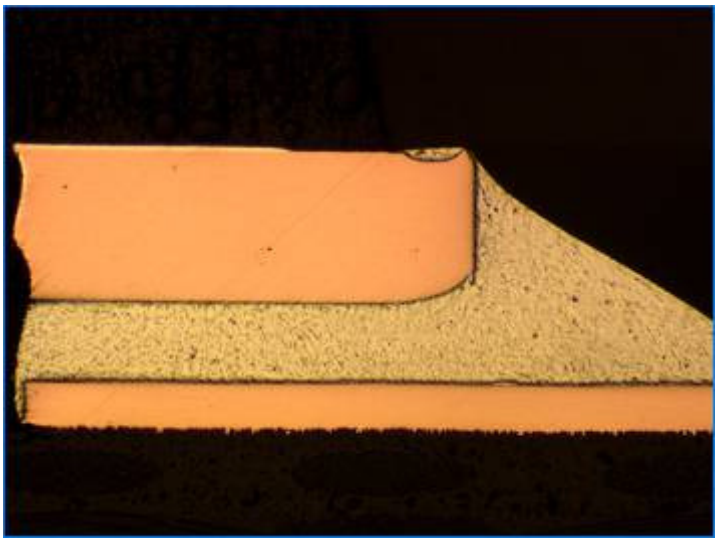

Figure 116: cross section, SN65, U54, right lead , 100x

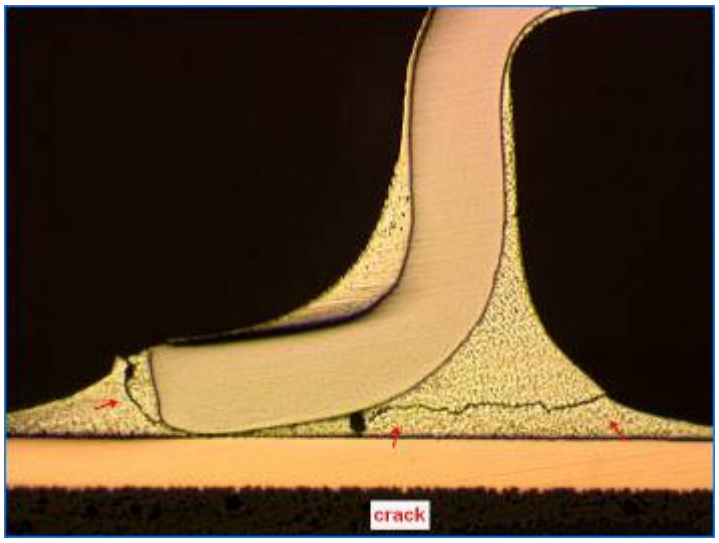

Figure 117: cross section, SN65, U61, left lead and solder crack, 100x

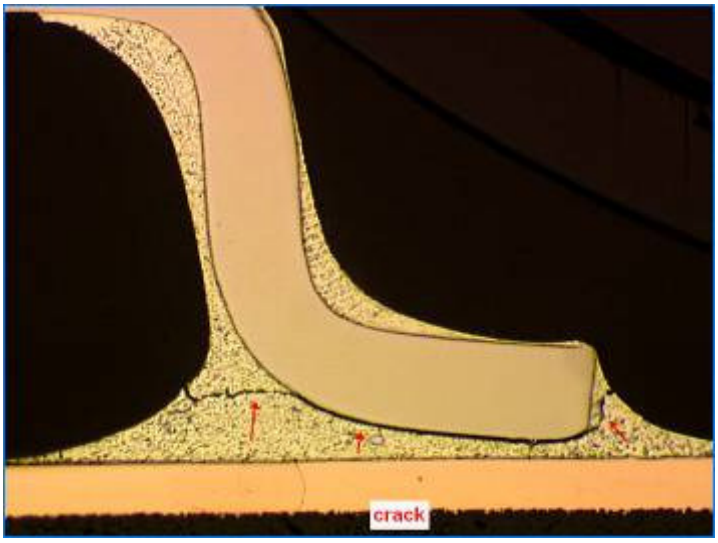

Figure 118: cross section, SN65, U61, right lead and solder crack, 100x

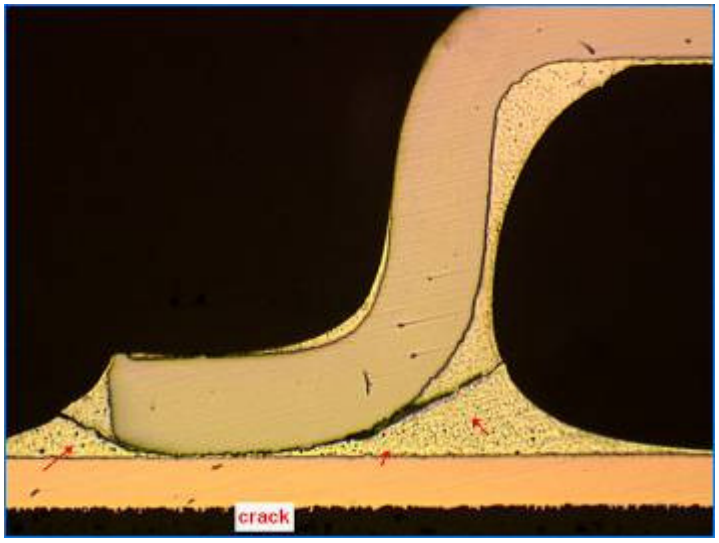

Figure 119: cross section, SN65, U62, left lead and solder crack, 100x

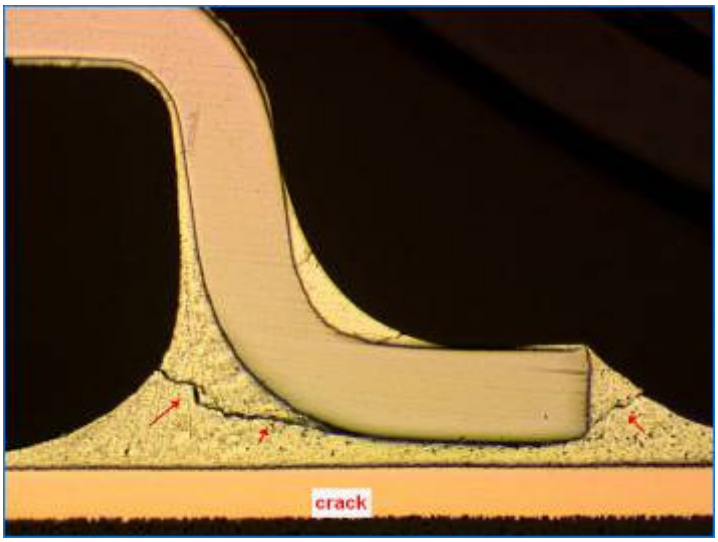

Figure 120: cross section, SN65, U62, right lead and solder crack, 100x

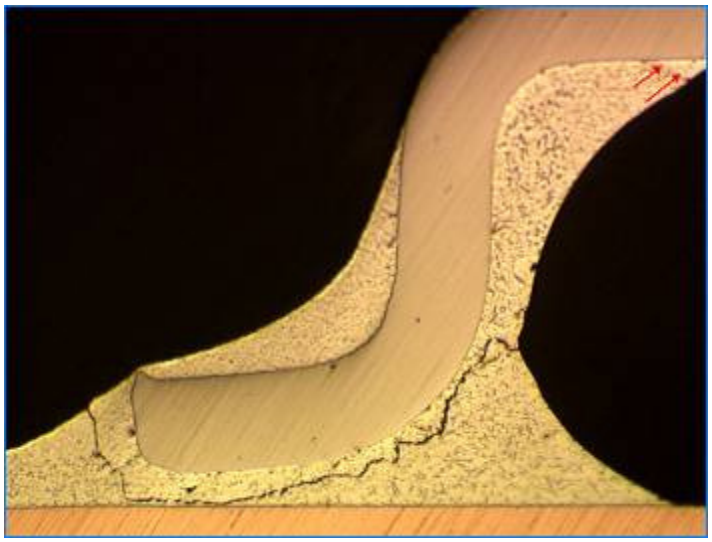

Figure 121: cross section, SN66, U61, left lead solder crack, 100x

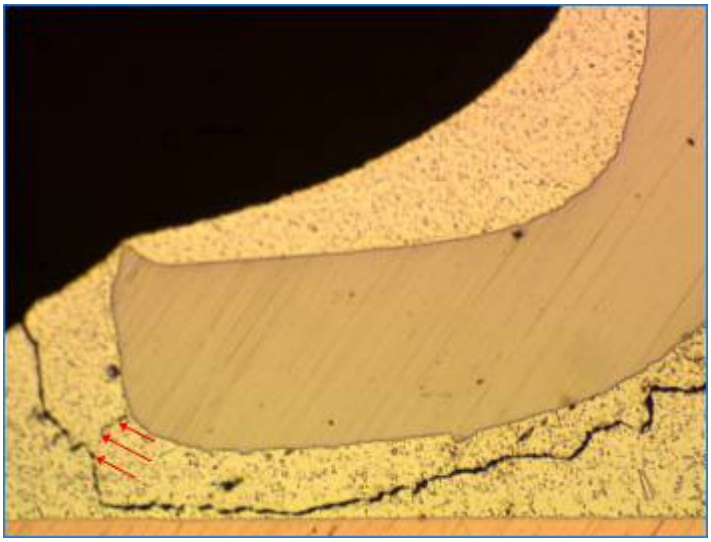

Figure 122: cross section, SN66, U61, left lead solder crack, 200xa

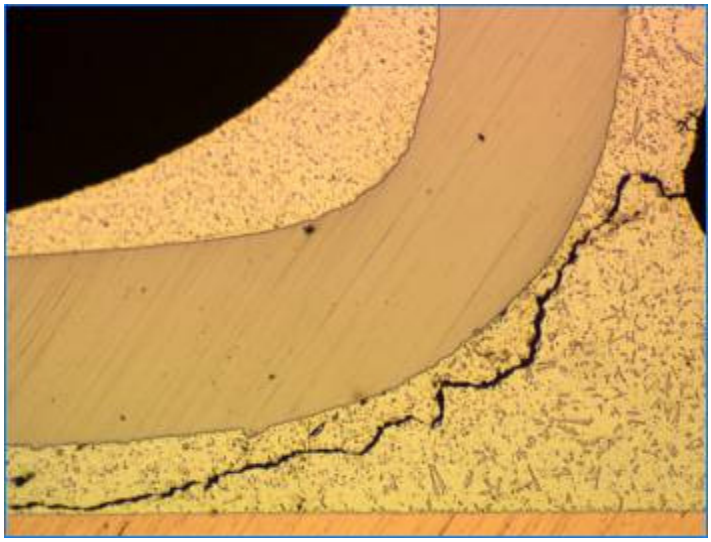

Figure 123: cross section, SN66, U61, left lead solder crack, 200xb

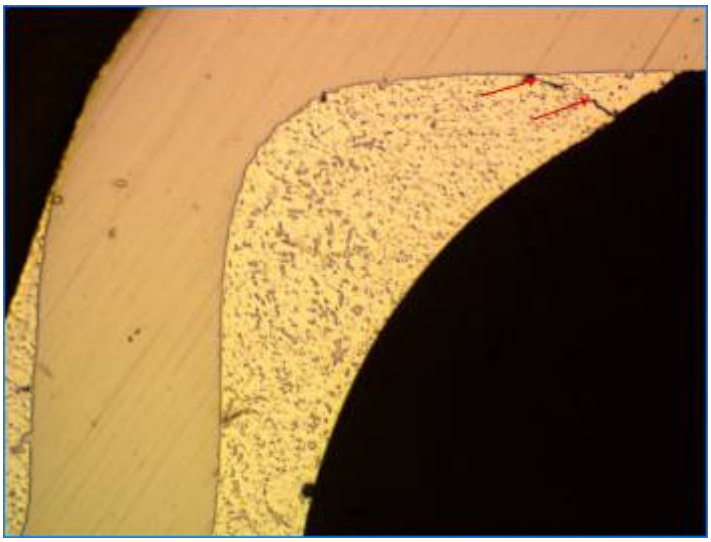

Figure 124: cross section, SN66, U61, left lead solder crack, 200xc

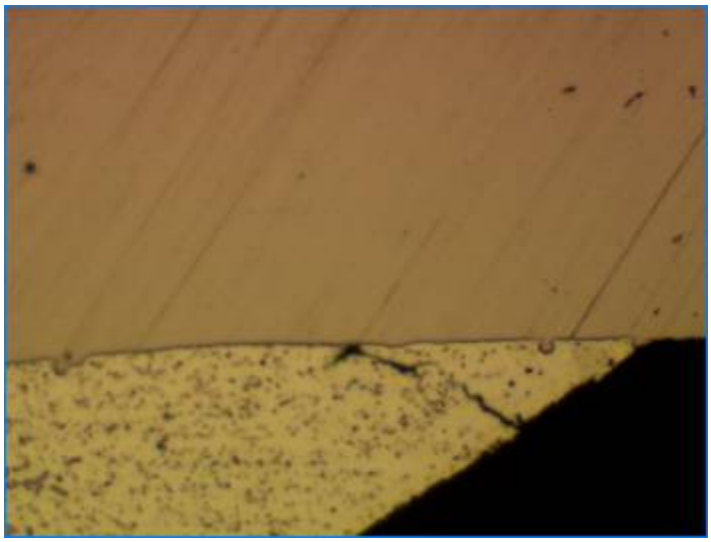

Figure 125: cross section, SN66, U61, left lead solder crack, 400x

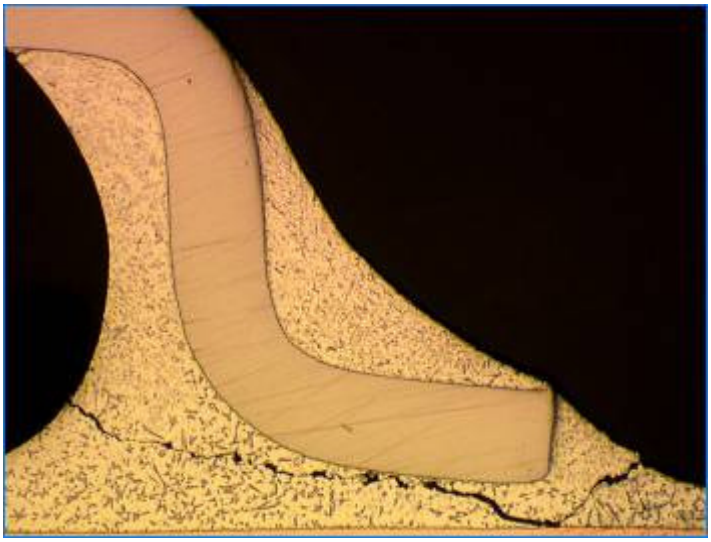

Figure 126: cross section, SN66, U61, right lead solder crack, 100x

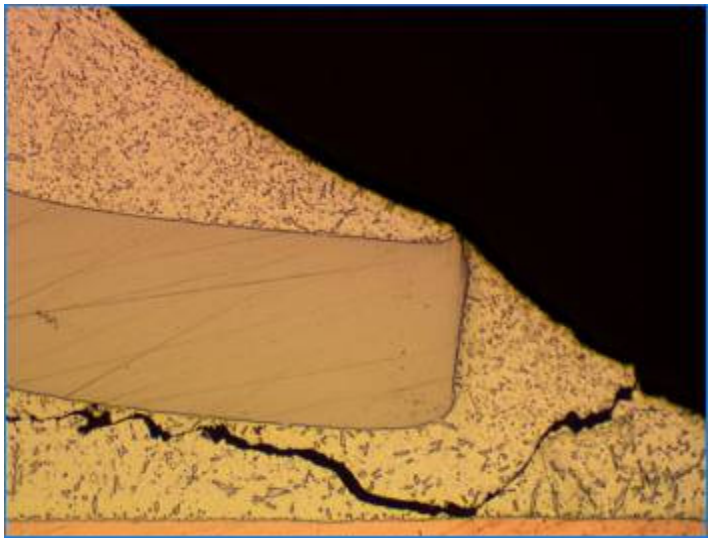

Figure 127: cross section, SN66, U61, right lead solder crack, 200xa

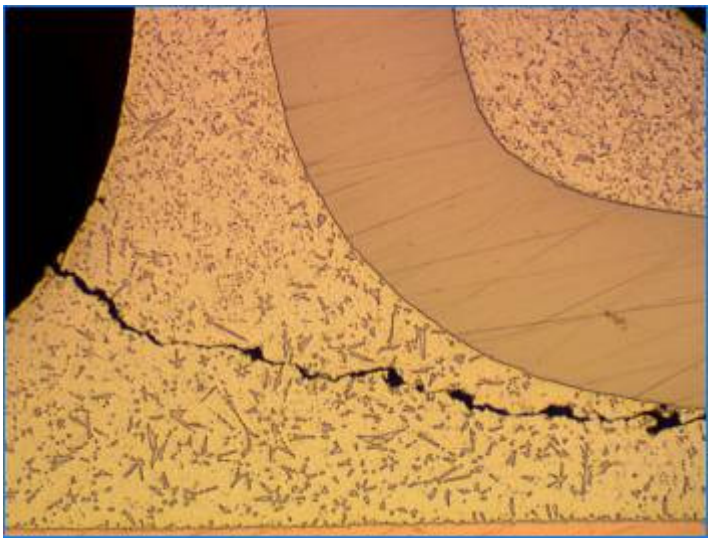

Figure 128: cross section, SN66, U61, right lead solder crack, 200xb

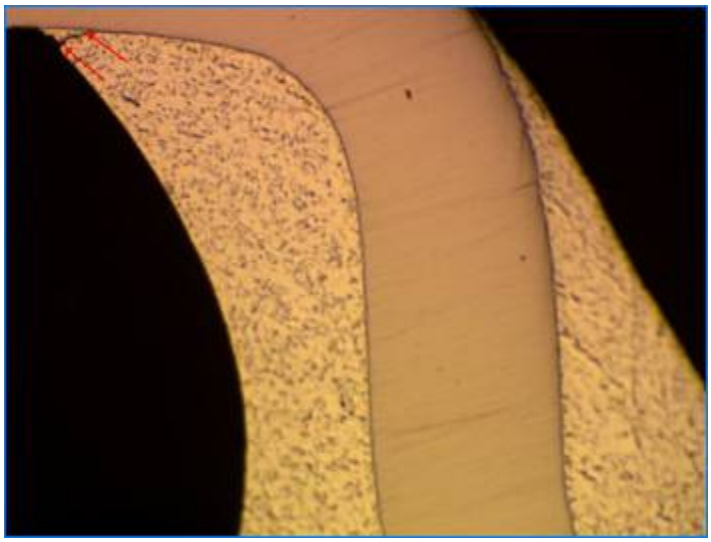

Figure 129: cross section, SN66, U61, right lead solder crack, 200xc

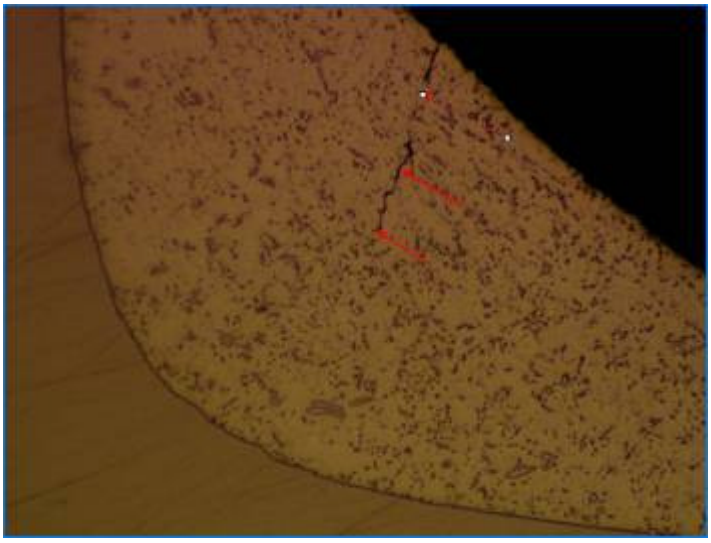

Figure 130: cross section, SN66, U61, right lead solder crack, 400x

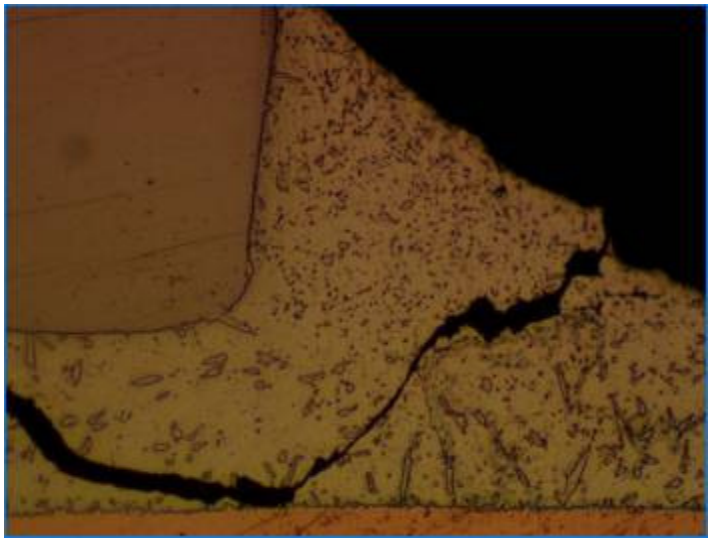

Figure 131: cross section, SN66, U61, right lead solder crack, 400xb

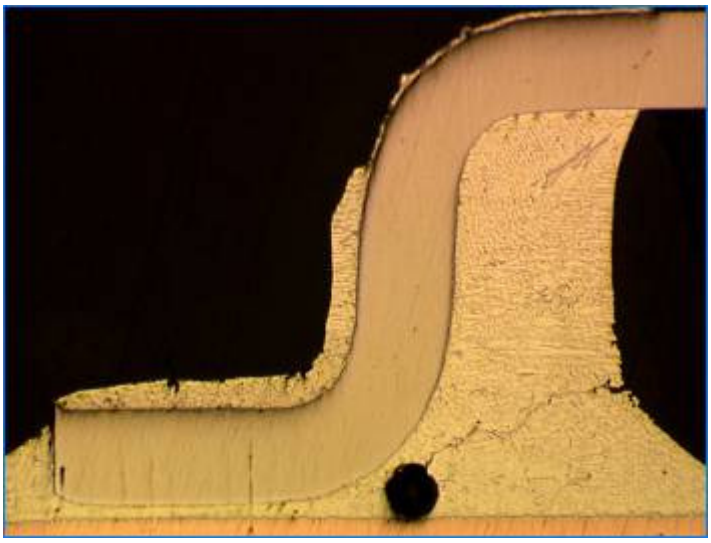

Figure 132: cross section, SN66, U62, left lead solder crack and void, 100x

Figure 133: cross section, SN66, U62, left lead solder crack and void, 200xb

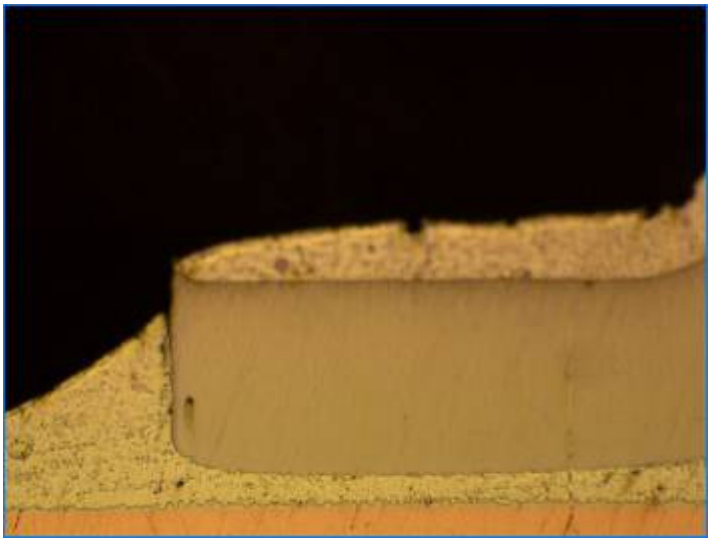

Figure 134: cross section, SN66, U62, left lead solder crack, 200xa

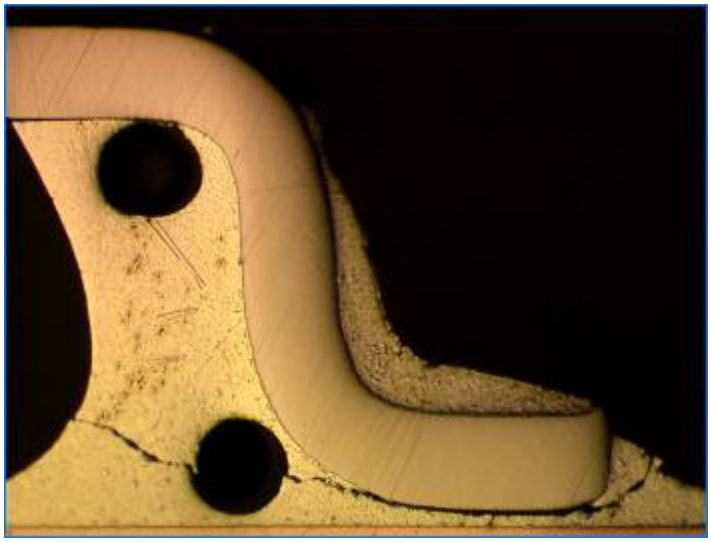

Figure 135: cross section, SN66, U62, right lead solder crack and void, 100x

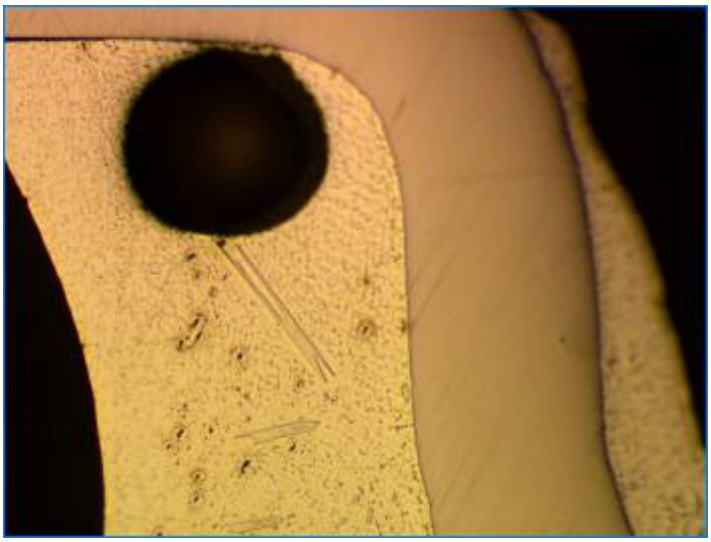

Figure 136: cross section, SN66, U62, right lead solder crack and void, 200xc

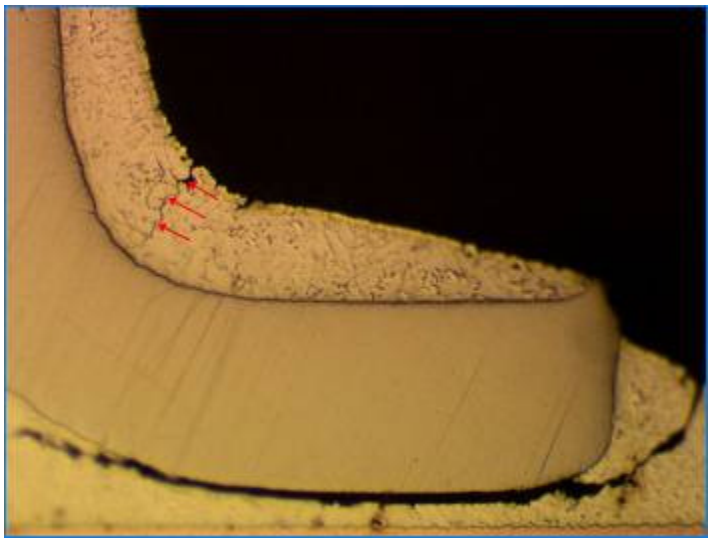

Figure 137: cross section, SN66, U62, right lead solder crack, 200xa

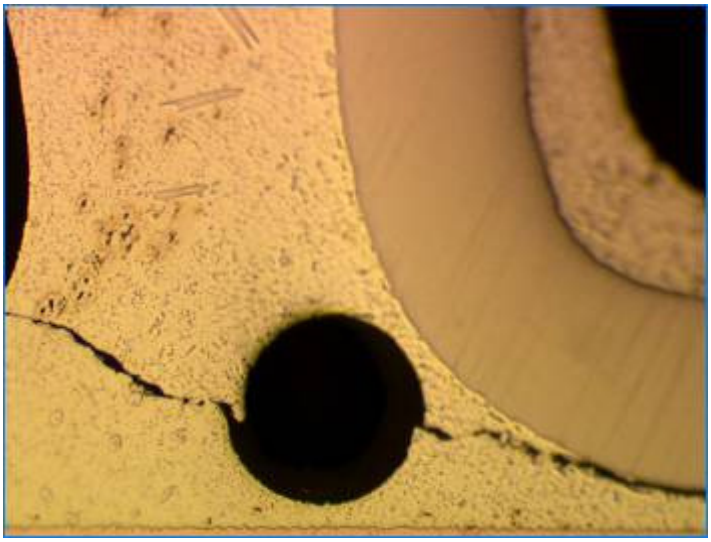

Figure 138: cross section, SN66, U62,right lead solder crack and void, 200xb

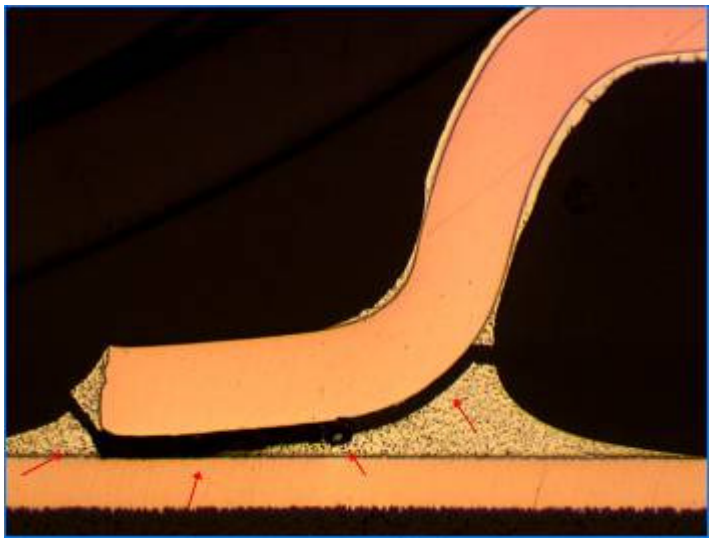

Figure 139: cross section, SN67, U31, left lead solder crack, 100x

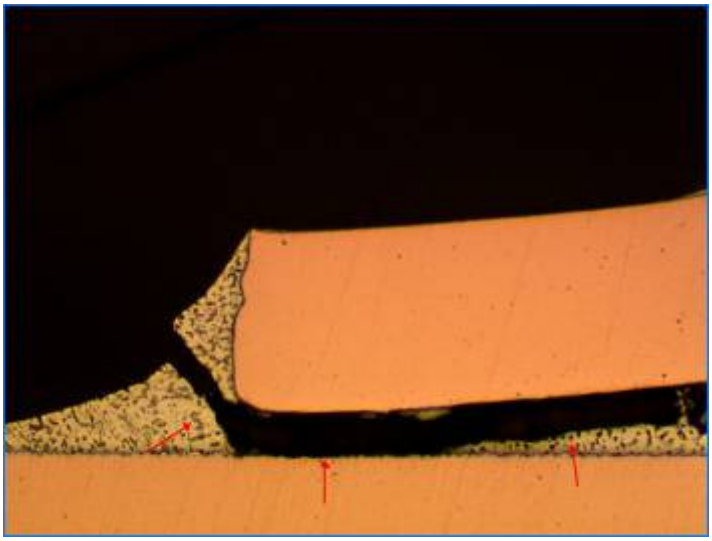

Figure 140: cross section, SN67, U31, left lead solder crack, 200xa

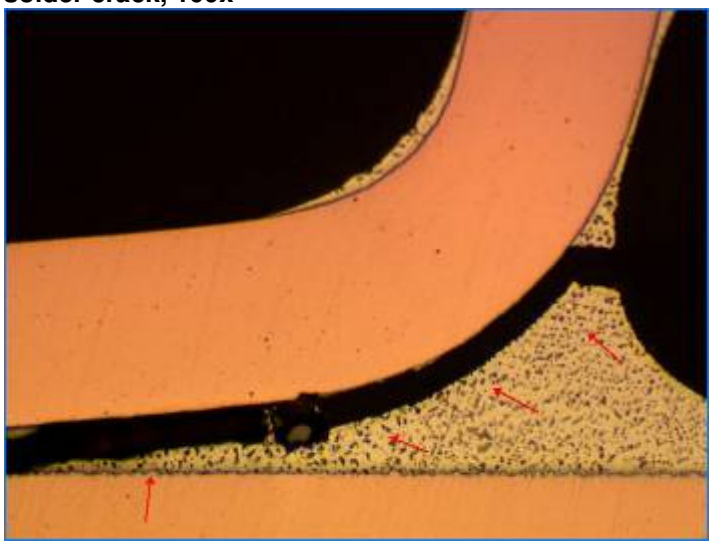

Figure 141: cross section, SN67, U31, left lead solder crack, 200xb

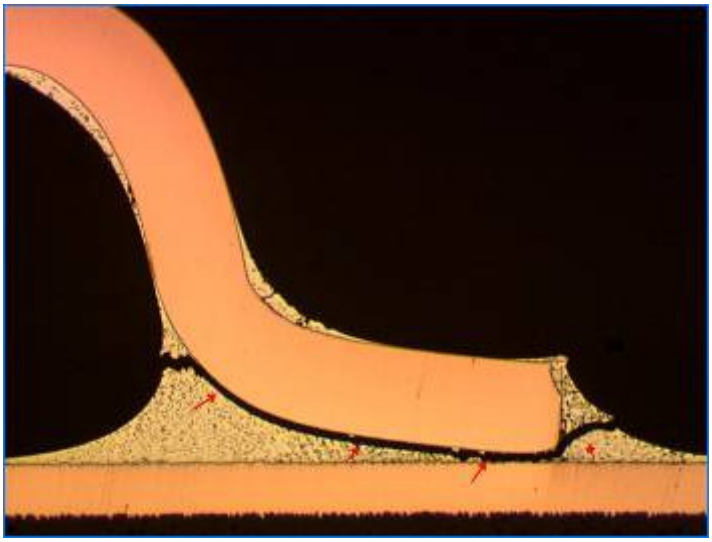

Figure 142: cross section, SN67, U31, right lead solder crack, 100x

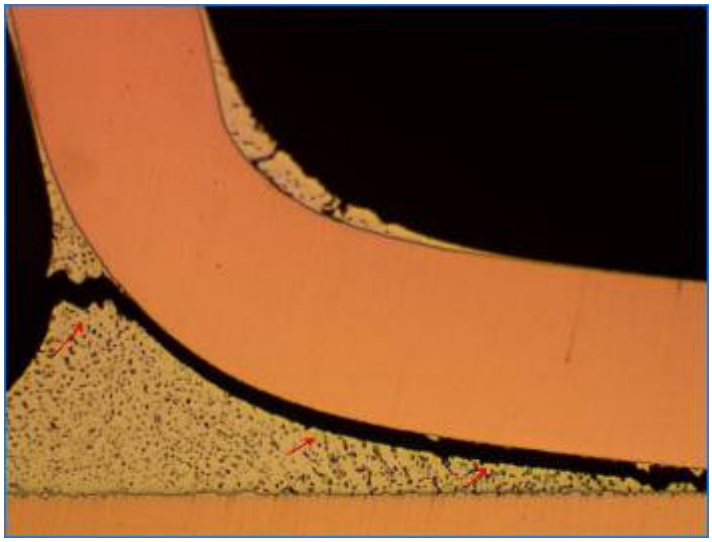

Figure 143: cross section, SN67, U31, right lead solder crack, 200xa

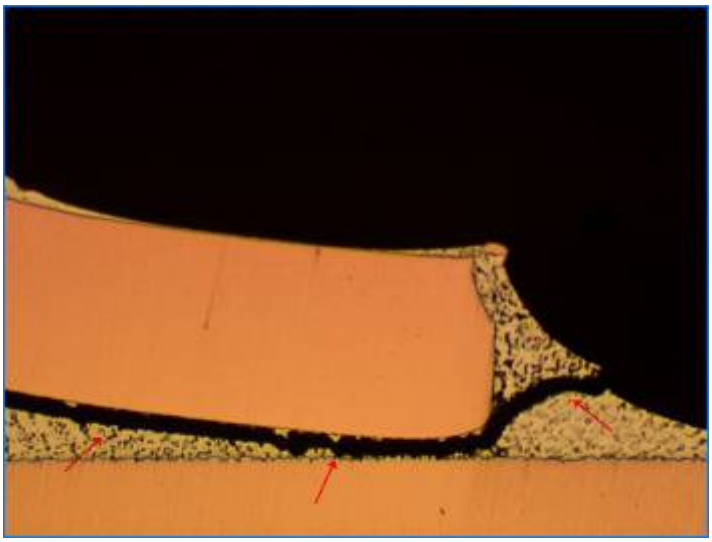

Figure 144: cross section, SN67, U31, right lead solder crack, 200xb

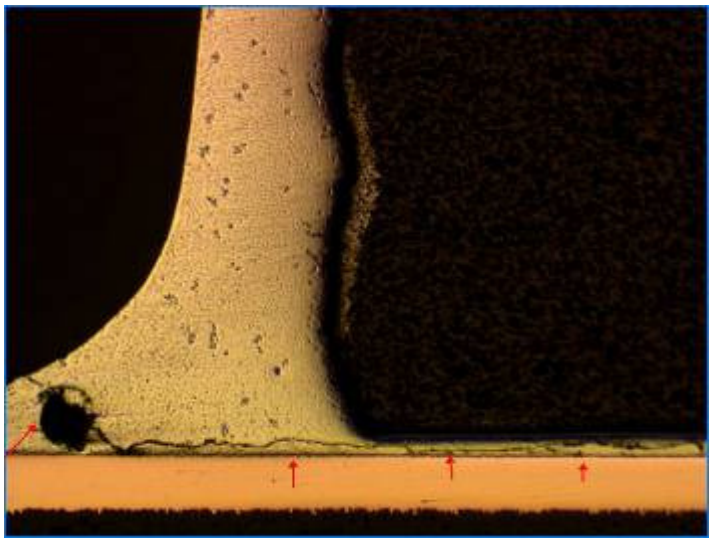

Figure 145: cross section, SN67, U52, left lead solder crack, 100x

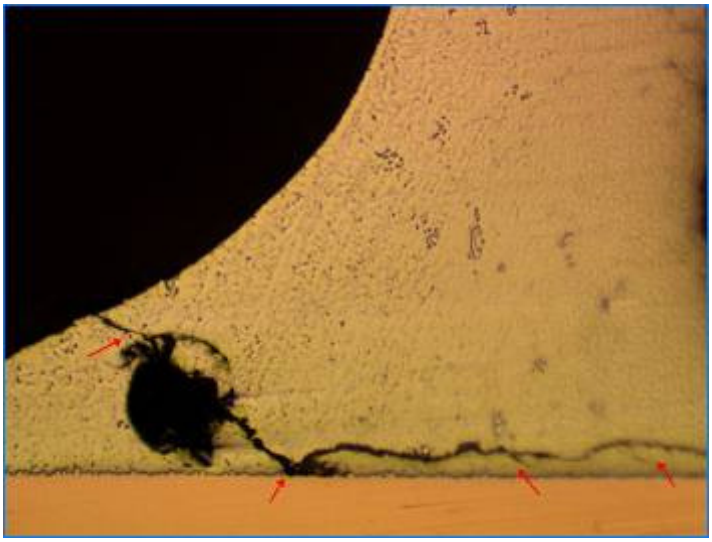

Figure 146: cross section, SN67, U52, left lead solder crack, 200xa

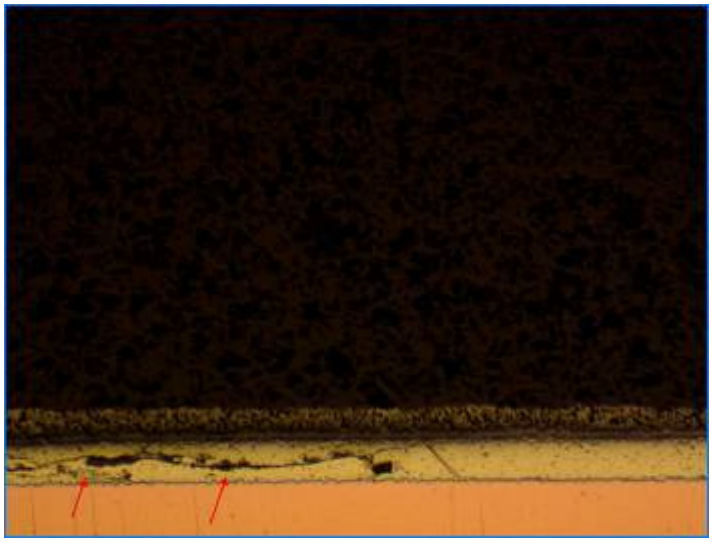

Figure 147: cross section, SN67, U52, left lead solder crack, 200xb

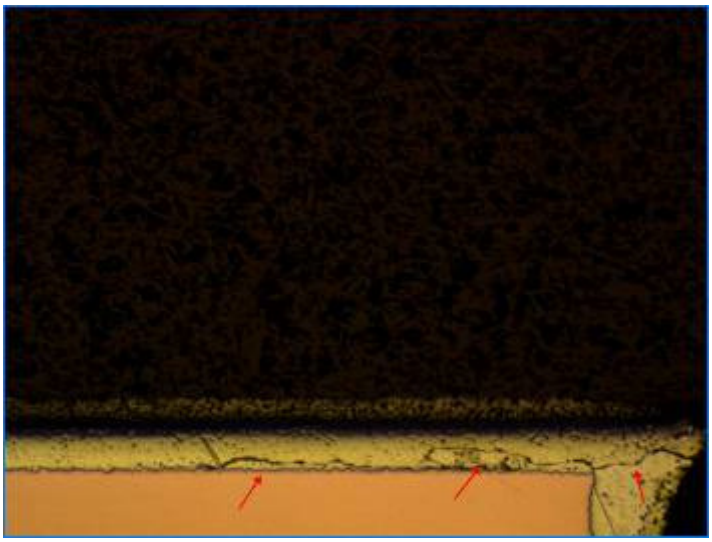

Figure 148: cross section, SN67, U52, left lead solder crack, 200xc partial

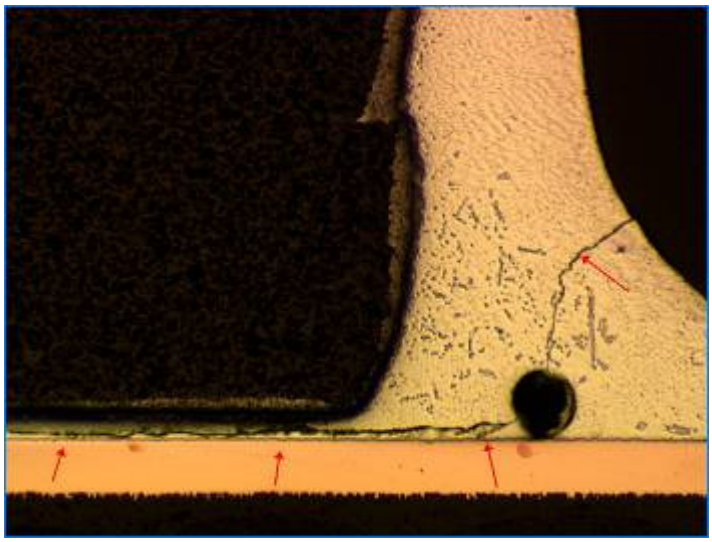

Figure 149: cross section, SN67, U52, right lead solder crack, 100x

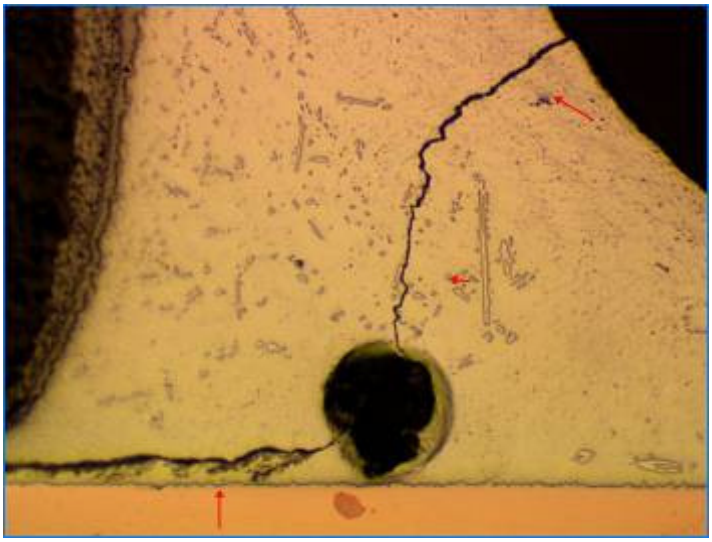

Figure 150: cross section, SN67, U52, right lead solder crack, 200xa

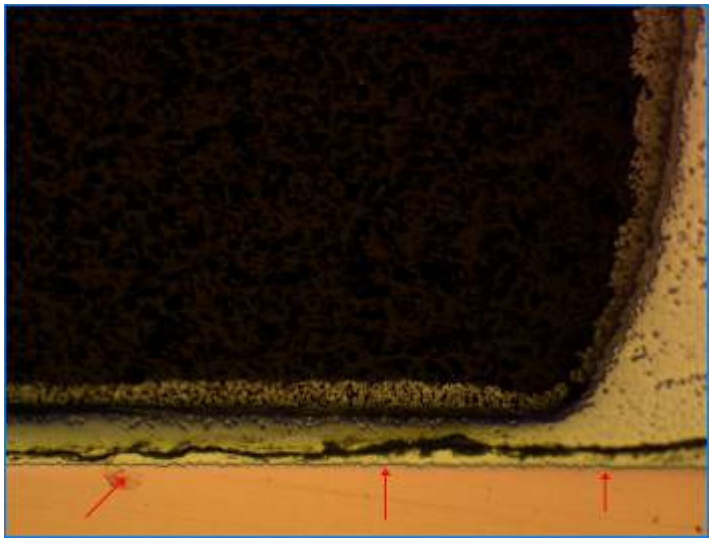

Figure 151: cross section, SN67, U52, right lead solder crack, 200xb

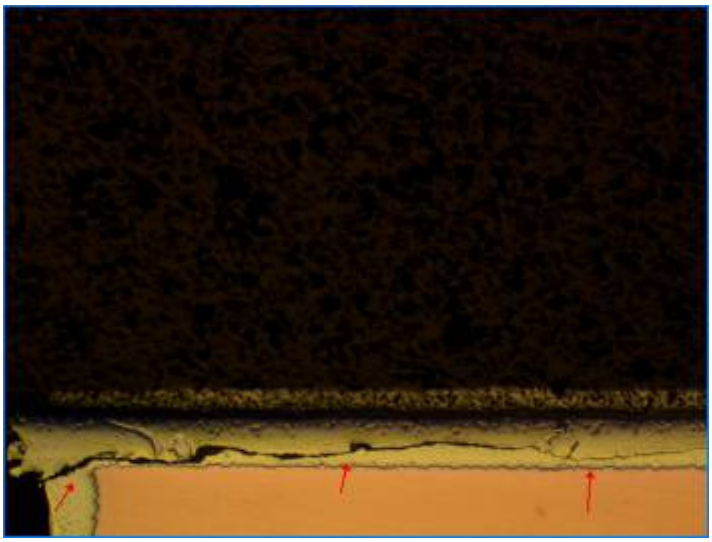

Figure 152: cross section, SN67, U52, right lead solder crack, 200xc

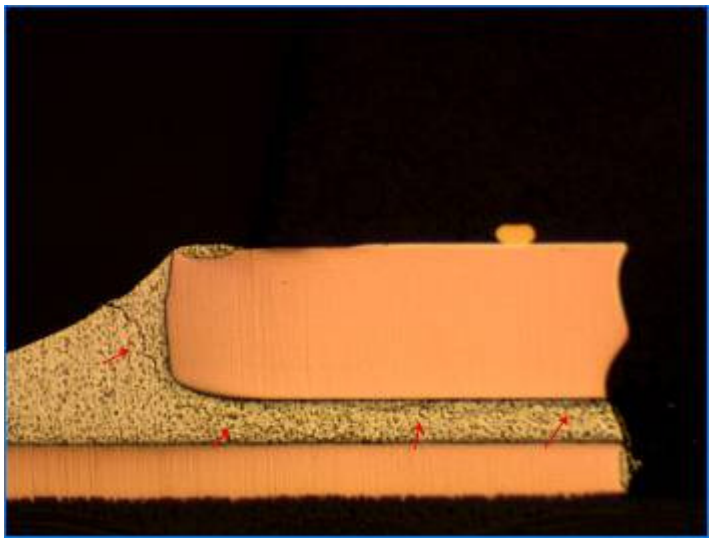

Figure 153: cross section, SN67, U54, left lead solder crack, 100x

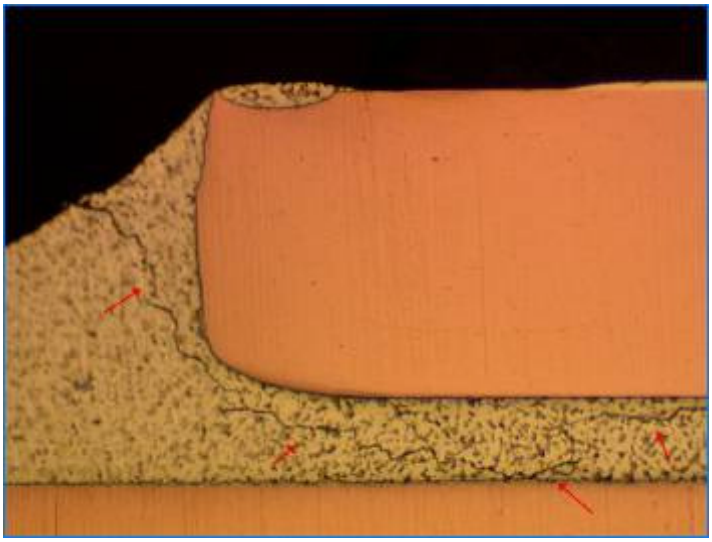

Figure 154: cross section, SN67, U54, left lead solder crack, 200xa

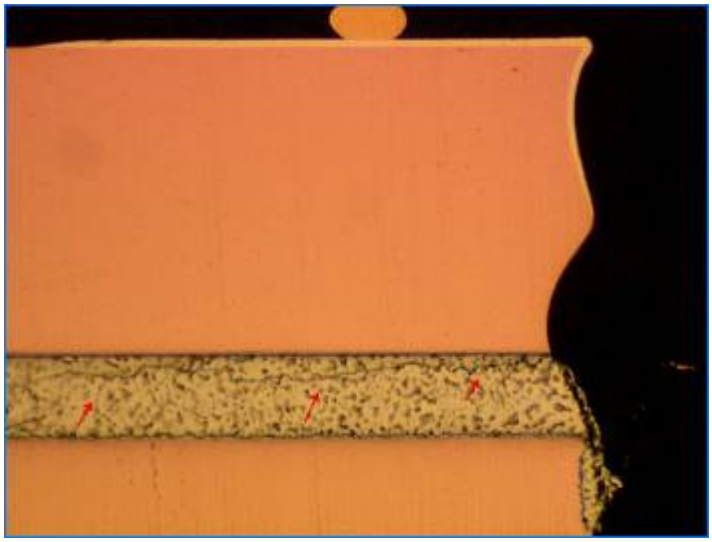

Figure 155: cross section, SN67, U54, left lead solder crack, 200xb

Figure 156: cross section, SN67, U54, right lead , 200xb

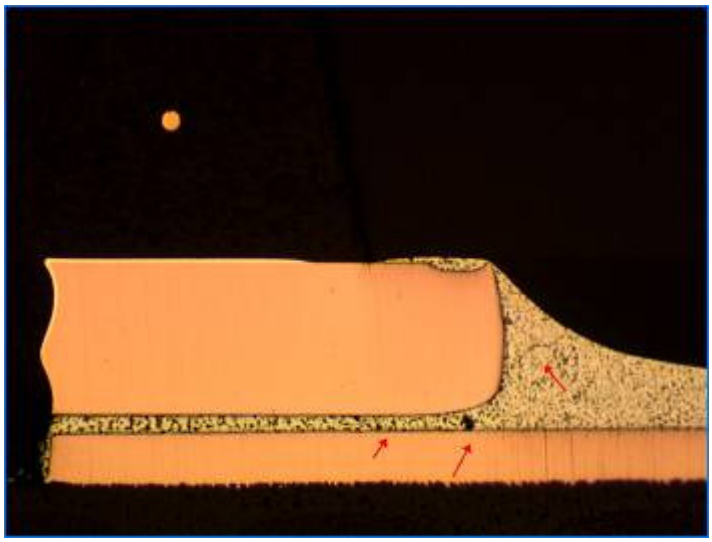

Figure 157: cross section, SN67, U54, right lead solder partial crack, 100x

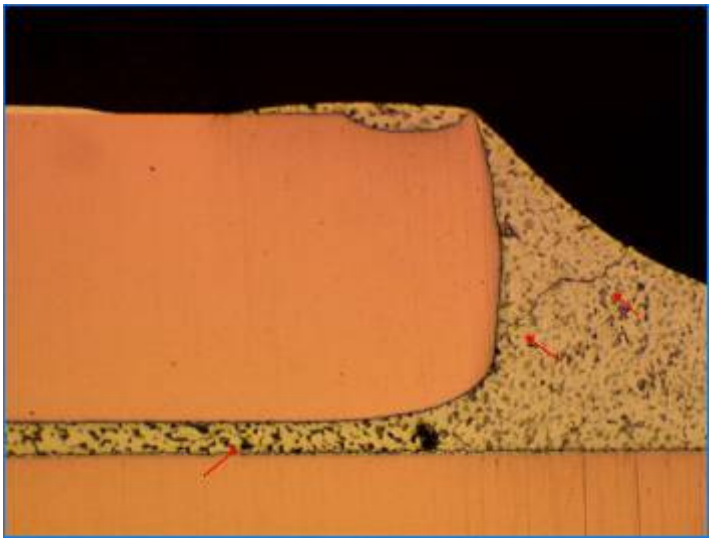

Figure 158: cross section, SN67, U54, right lead solder partial crack, 200xa

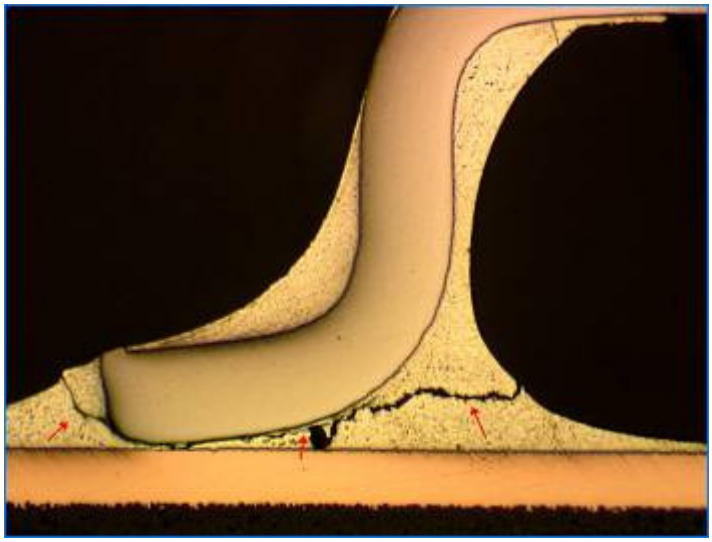

Figure 159: cross section, SN67, U61, left lead solder crack, 100x

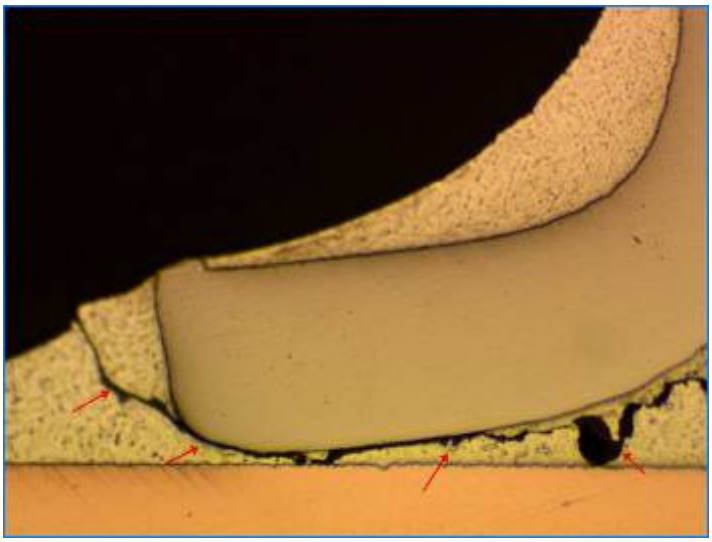

Figure 160: cross section, SN67, U61, left lead solder crack, 200xa

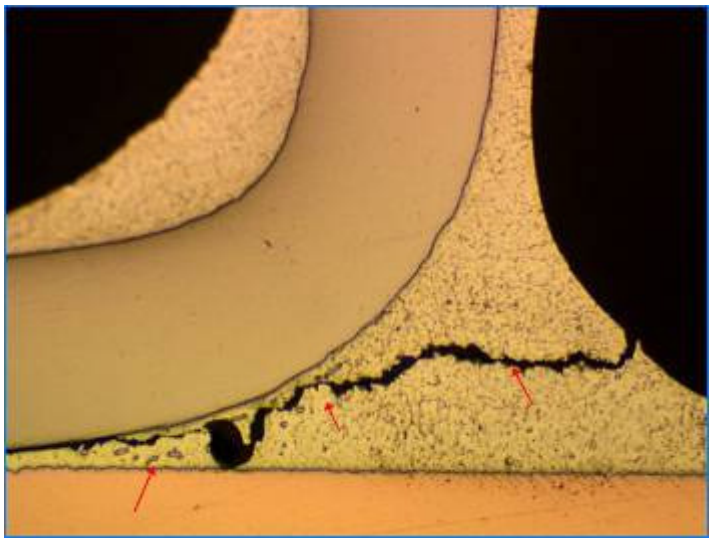

Figure 161: cross section, SN67, U61, left lead solder crack, 200xb

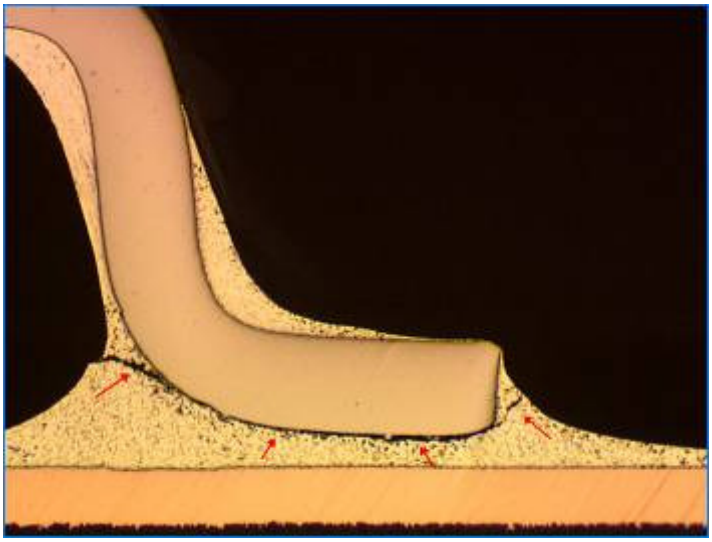

Figure 162: cross section, SN67, U61, right lead solder crack, 100x

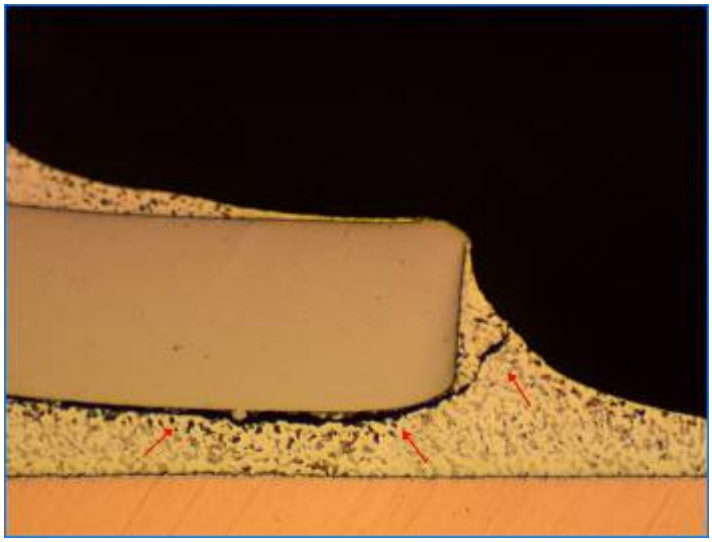

Figure 163: cross section, SN67, U61, right lead solder crack, 200xa

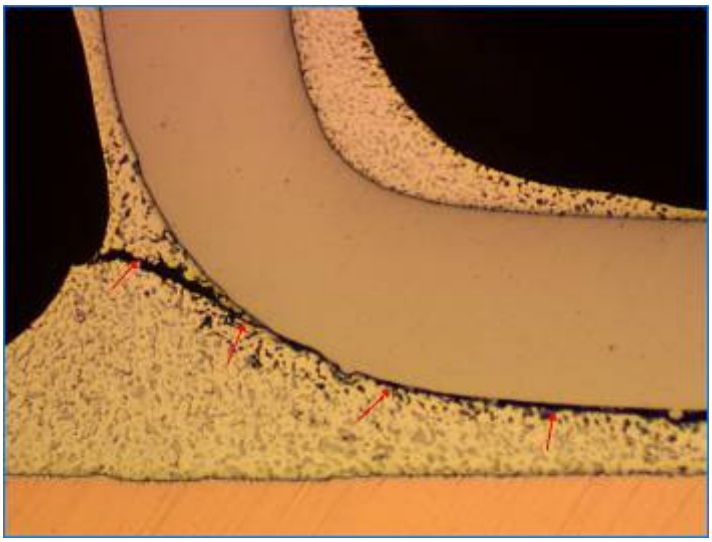

Figure 164: cross section, SN67, U61, right lead solder crack, 200xb

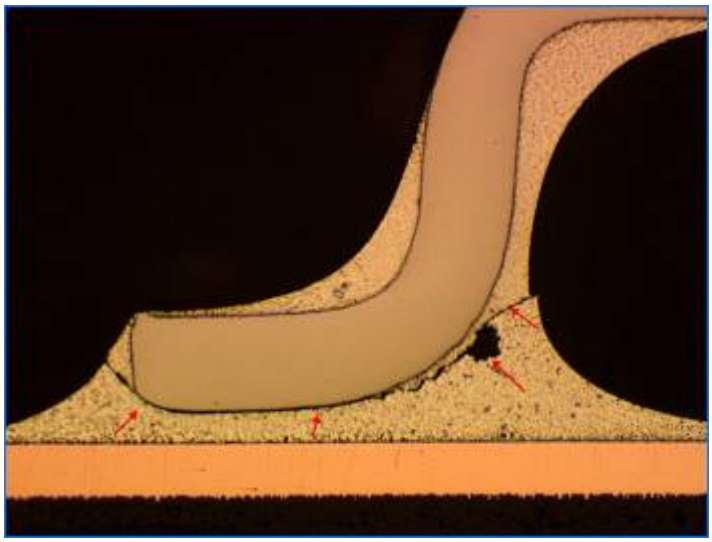

Figure 165: cross section, SN67, U62, left lead solder crack, 100x

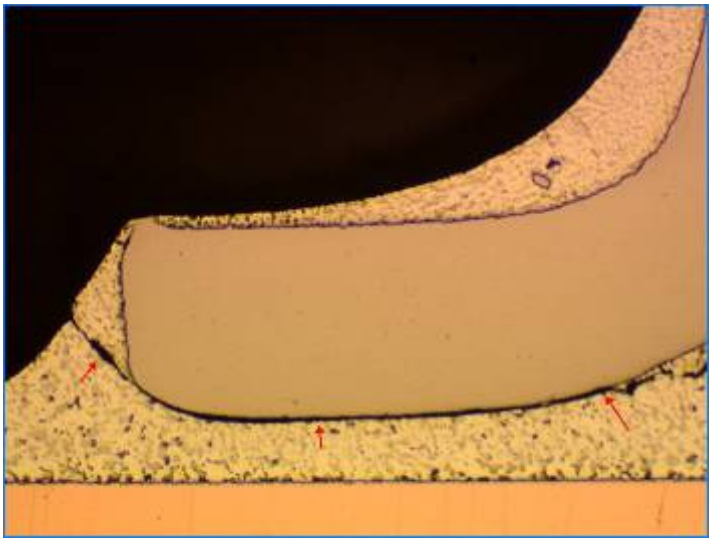

Figure 166: cross section, SN67, U62, left lead solder crack, 200xa

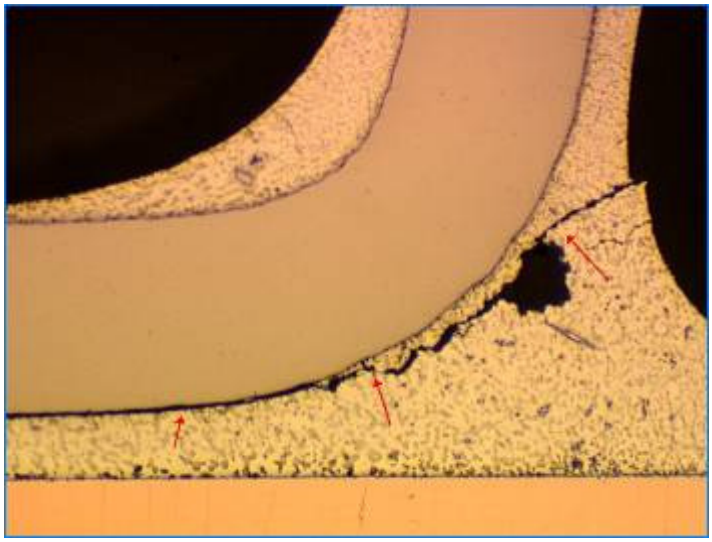

Figure 167: cross section, SN67, U62, left lead solder crack, 200xb

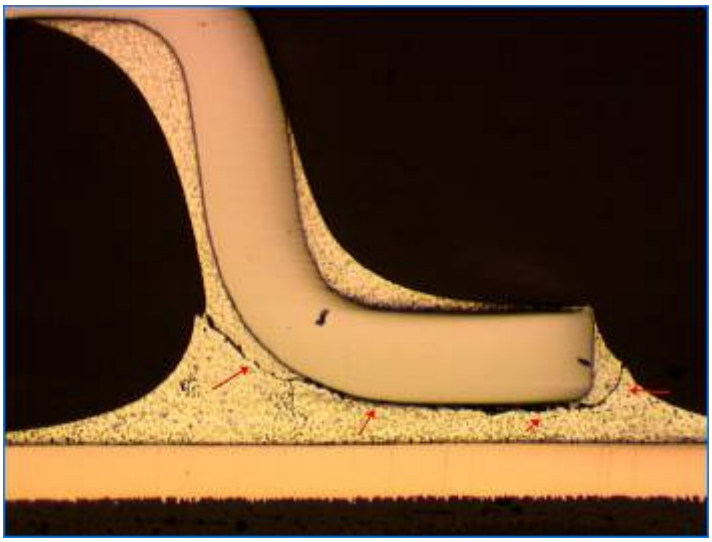

Figure 168: cross section, SN67, U62, right lead solder crack, 100x

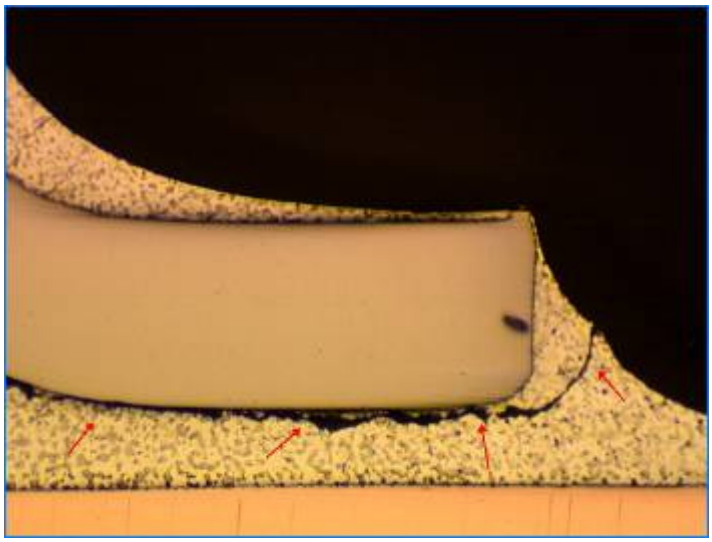

Figure 169: cross section, SN67, U62, right lead solder crack, 200xa

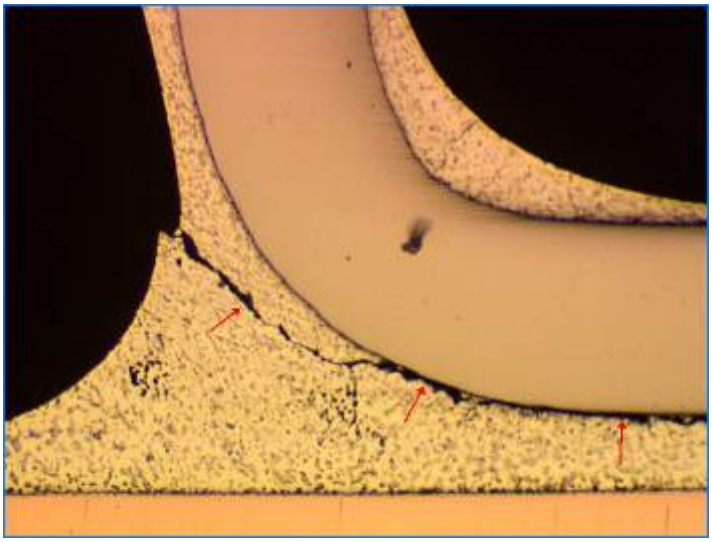

Figure 170: cross section, SN67, U62, right lead solder crack, 200xb

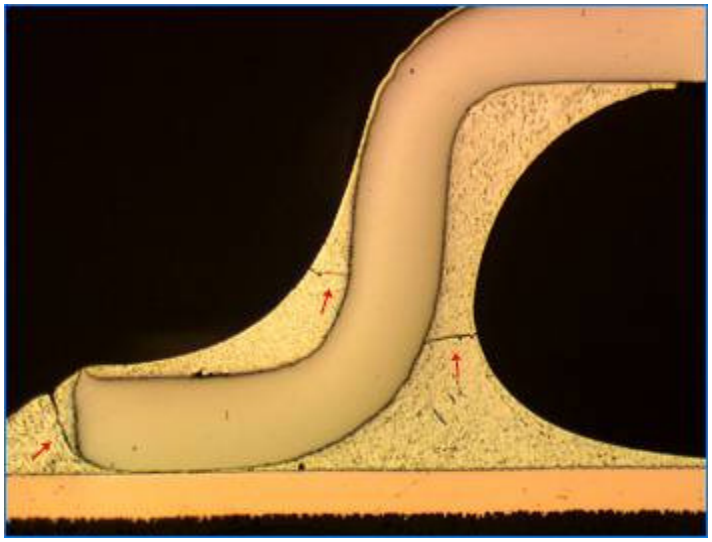

Figure 171: cross section, SN68, U16, left lead solder partial crack, 100x

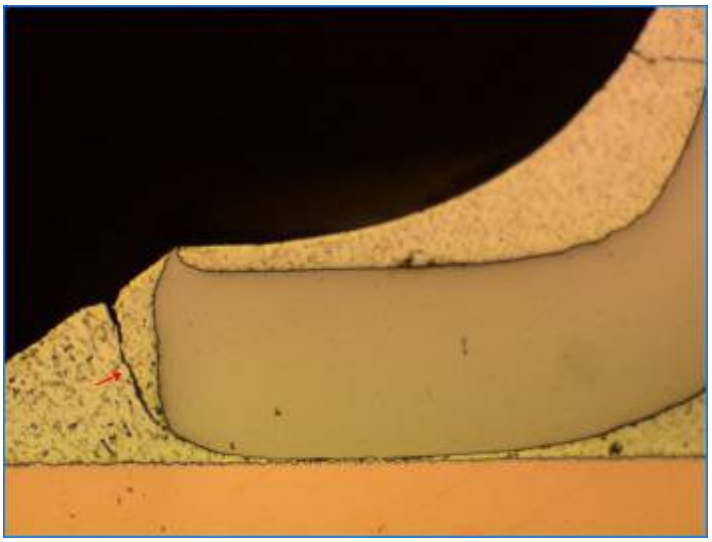

Figure 172: cross section, SN68, U16, left lead solder partial crack, 200xa

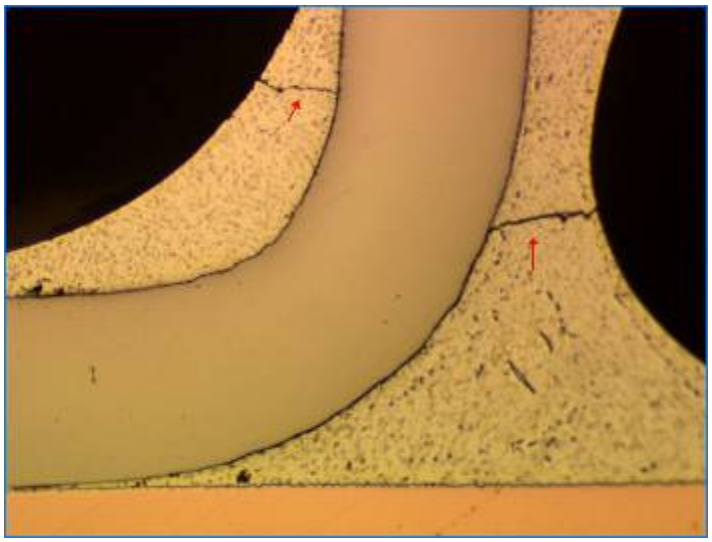

Figure 173: cross section, SN68, U16, left lead solder partial crack, 200xb

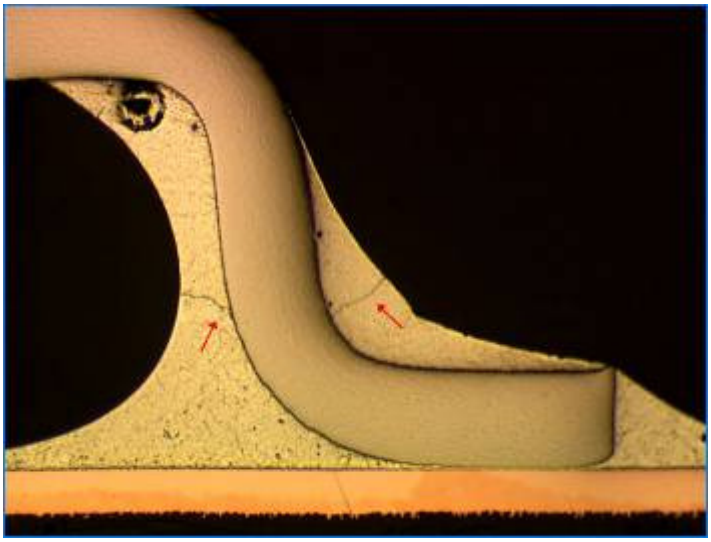

Figure 174: cross section, SN68, U16, right lead solder partial crack, 100x

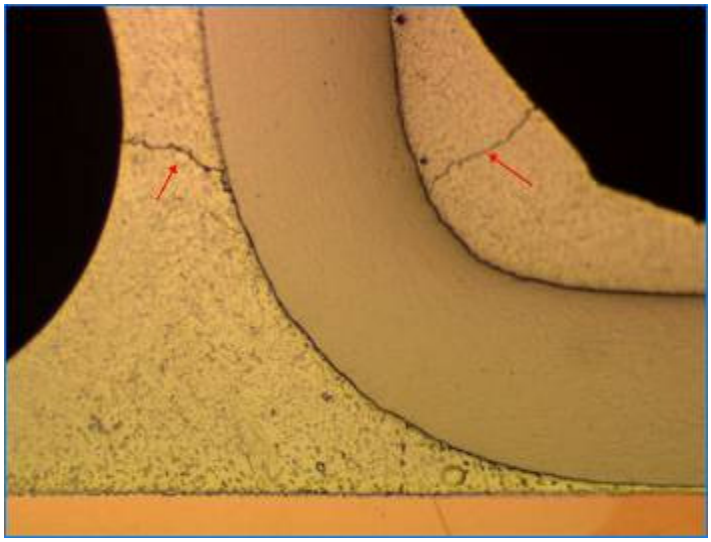

Figure 175: cross section, SN68, U16, right lead solder partial crack, 200x

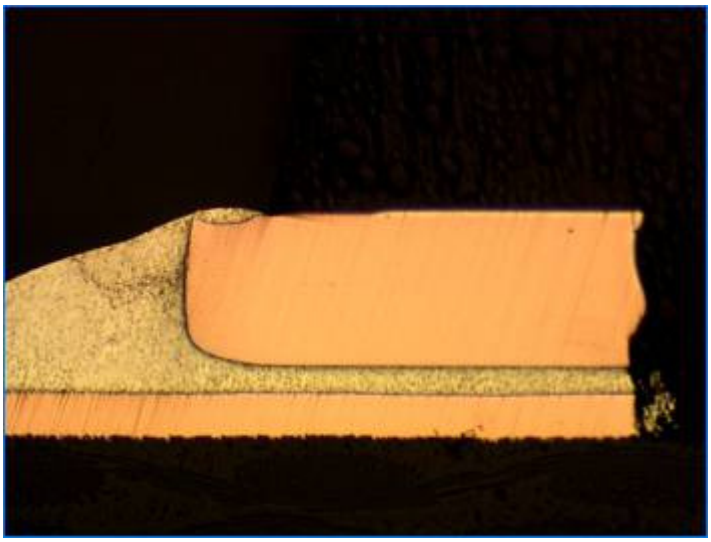

Figure 176: cross section, SN68, U28, left lead, 100x

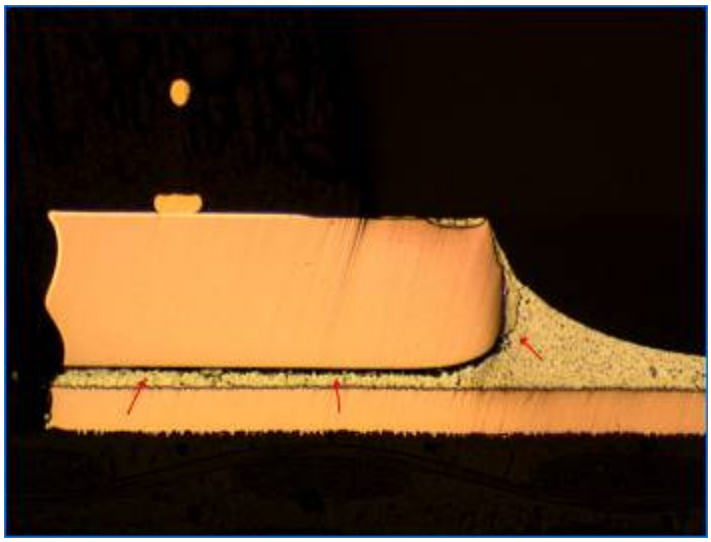

Figure 177: cross section, SN68, U28, right lead solder crack, 100x

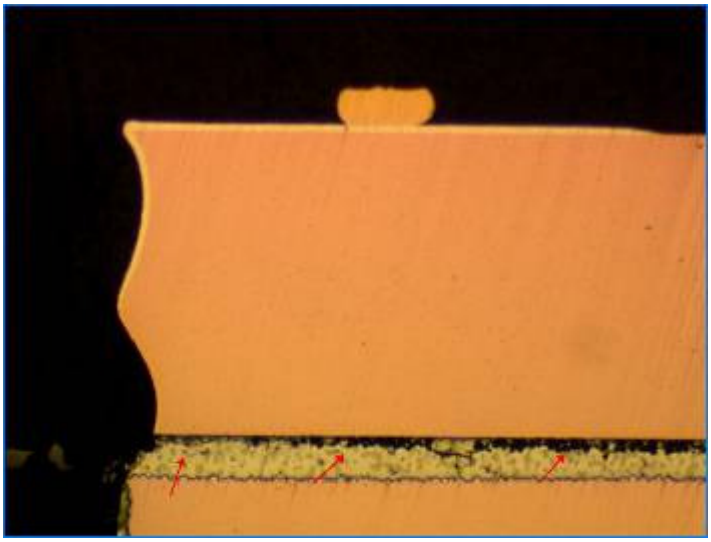

Figure 178: cross section, SN68, U28, right lead solder crack, 200xa

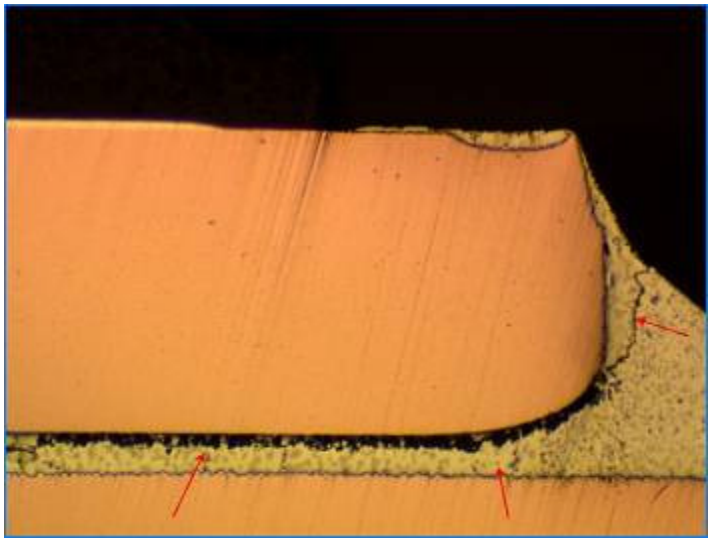

Figure 179: cross section, SN68, U28, right lead solder crack, 200xb

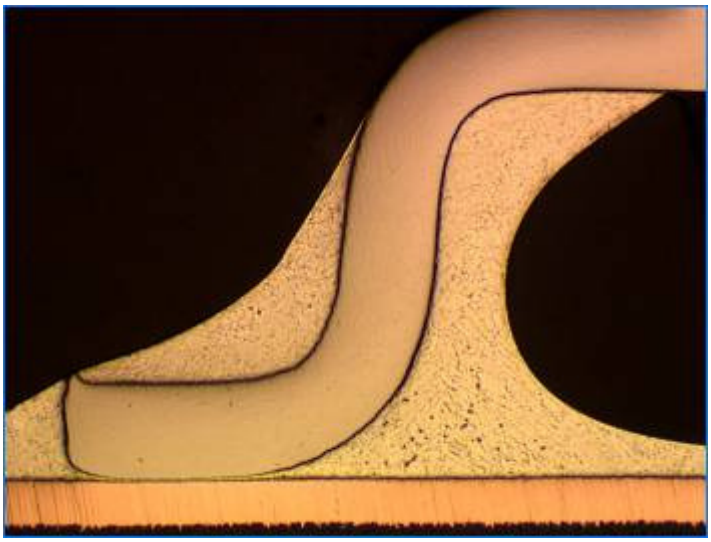

Figure 180: cross section, SN68, U29, left lead , 100x

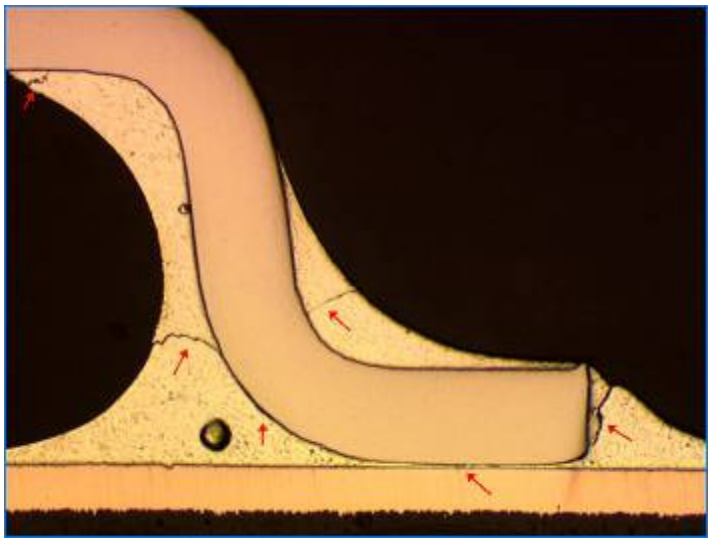

Figure 181: cross section, SN68, U29, right lead solder crack, 100x

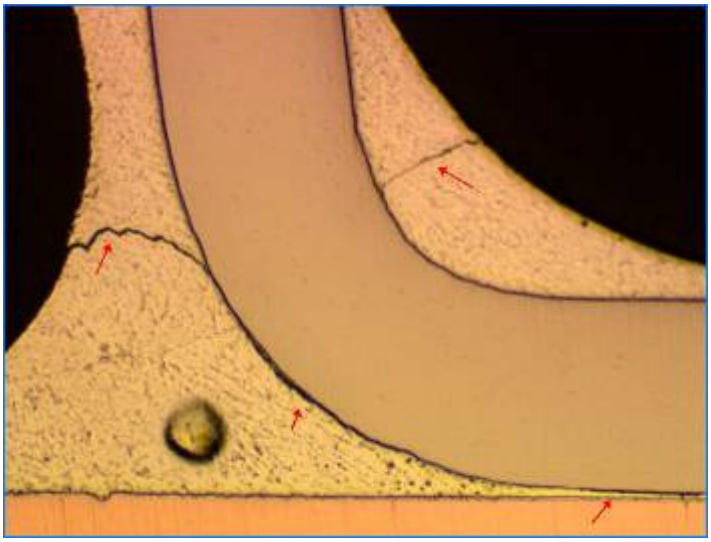

Figure 182: cross section, SN68, U29, right lead solder crack, 200xa

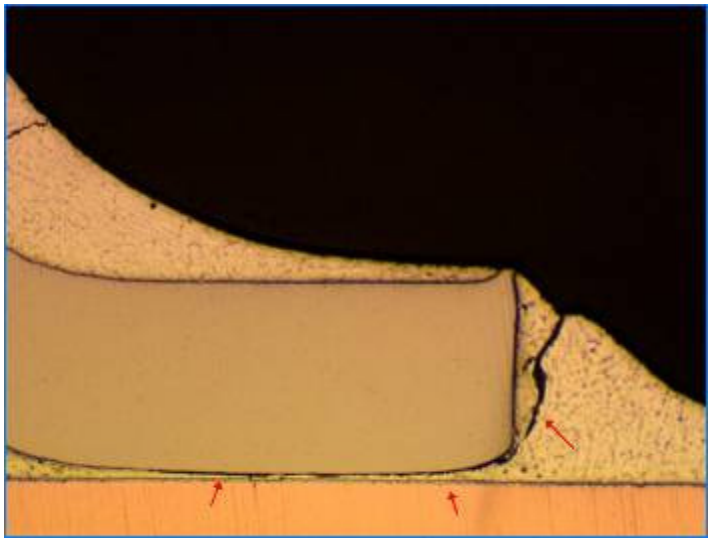

Figure 183: cross section, SN68, U29, right lead solder crack, 200xb

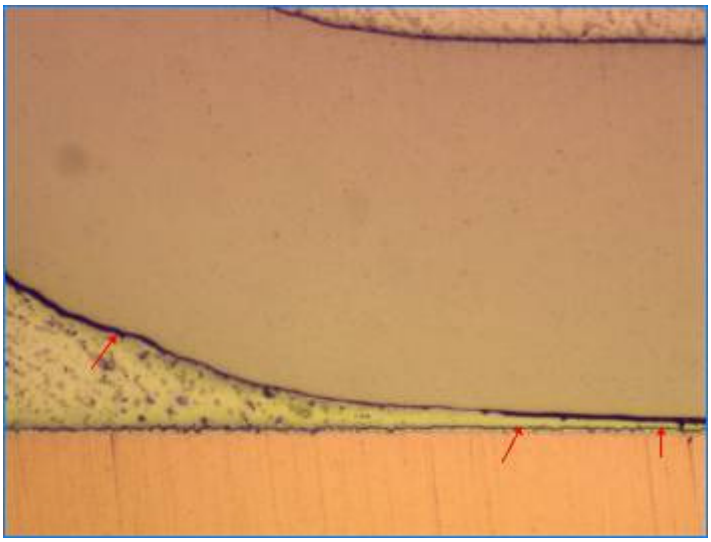

Figure 184: cross section, SN68, U29, right lead solder crack, betwen lead and pad,400x

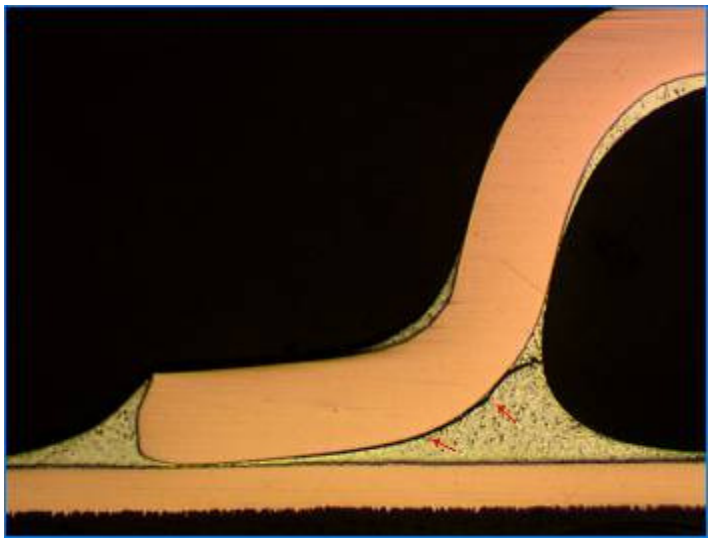

Figure 185: cross section, SN68, U31, left lead solder partial crack, 100x

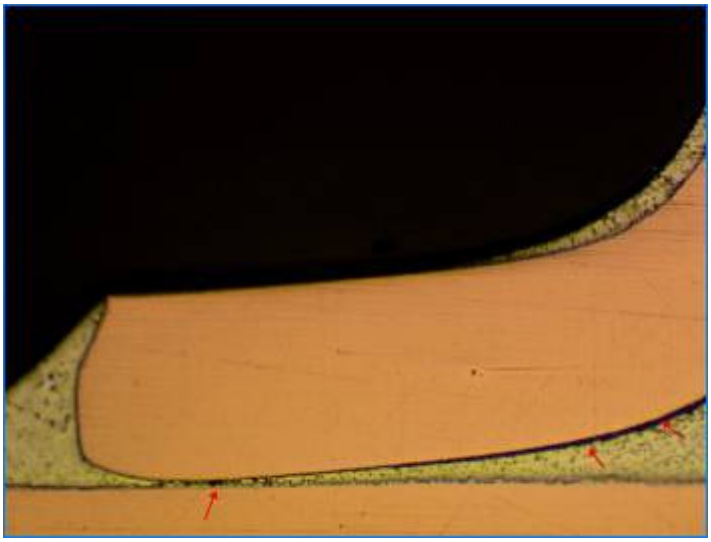

Figure 186: cross section, SN68, U31, left lead solder partial crack, 200xa

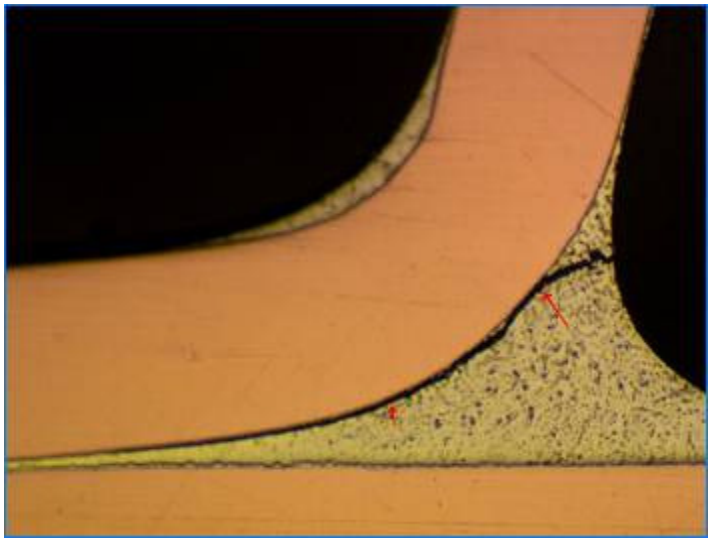

Figure 187: cross section, SN68, U31, left lead solder partial crack, 200xb

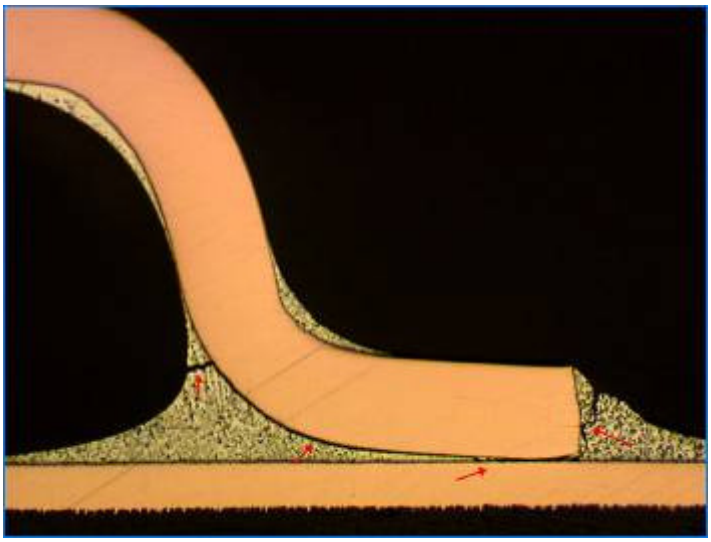

Figure 188: cross section, SN68, U31, right lead solder crack, 100x

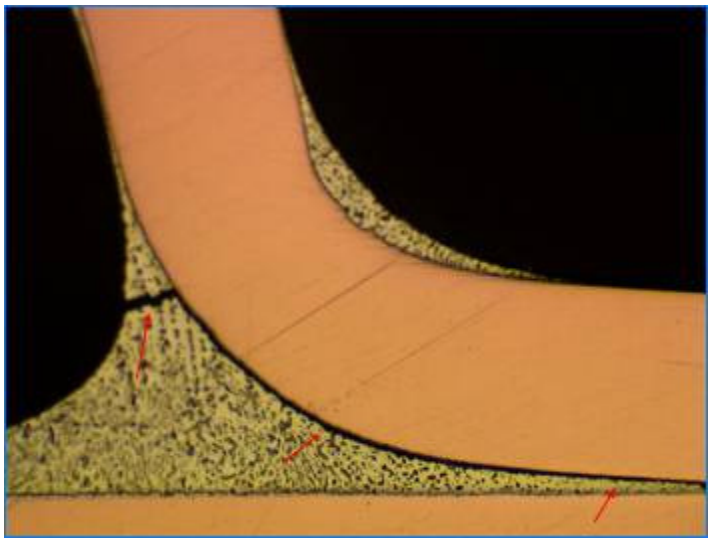

Figure 189: cross section, SN68, U31, right lead solder crack, 200xa

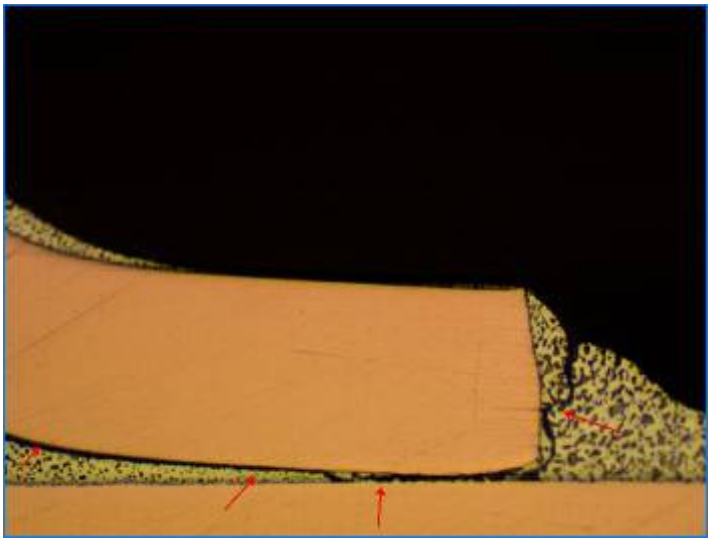

Figure 190: cross section, SN68, U31, right lead solder crack, 200xb

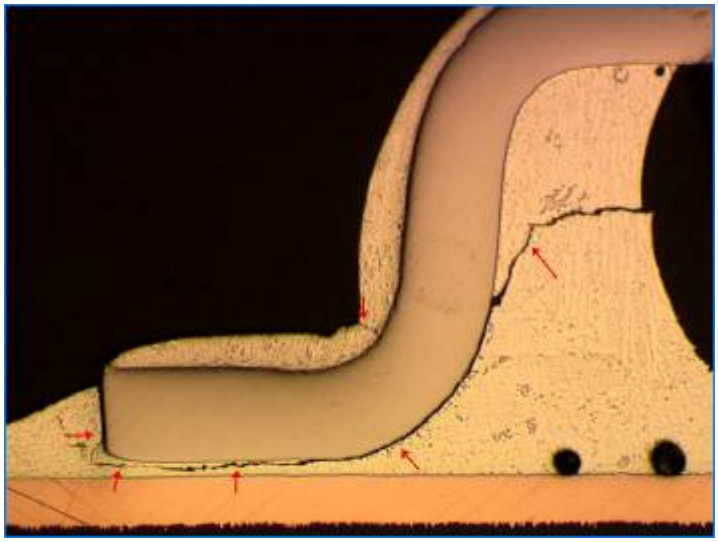

Figure 191: cross section, SN79, U12, left lead solder crack, 100x

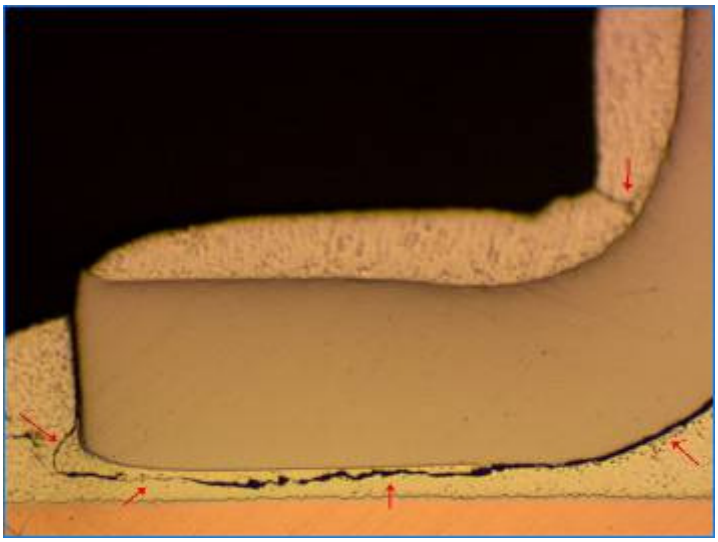

Figure 192: cross section, SN79, U12, left lead solder crack, 200xa

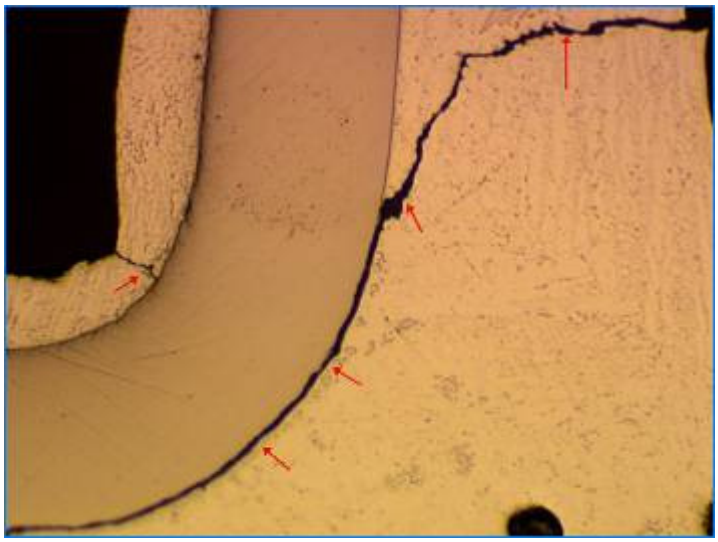

Figure 193: cross section, SN79, U12, left lead solder crack, 200xb

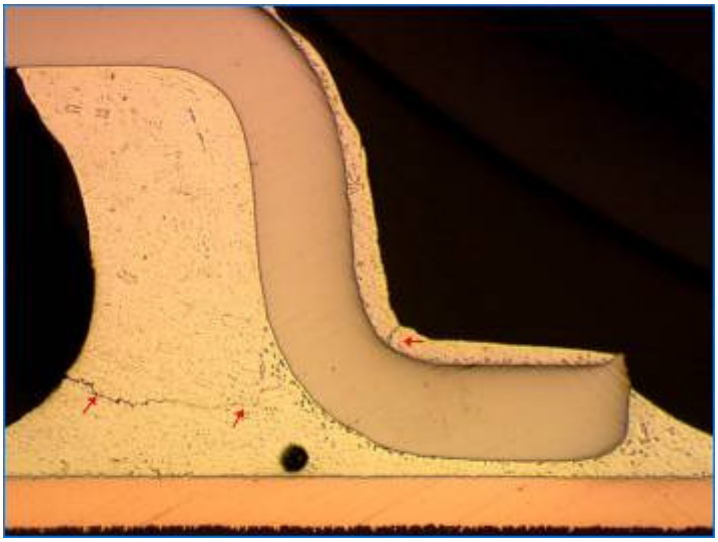

Figure 194: cross section, SN79, U12, right lead solder partial crack, 100x

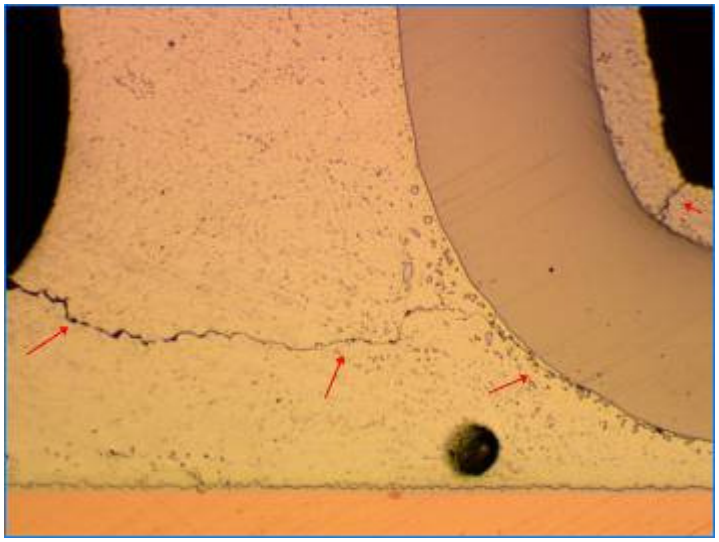

Figure 195: cross section, SN79, U12, right lead solder partial crack, 200xa

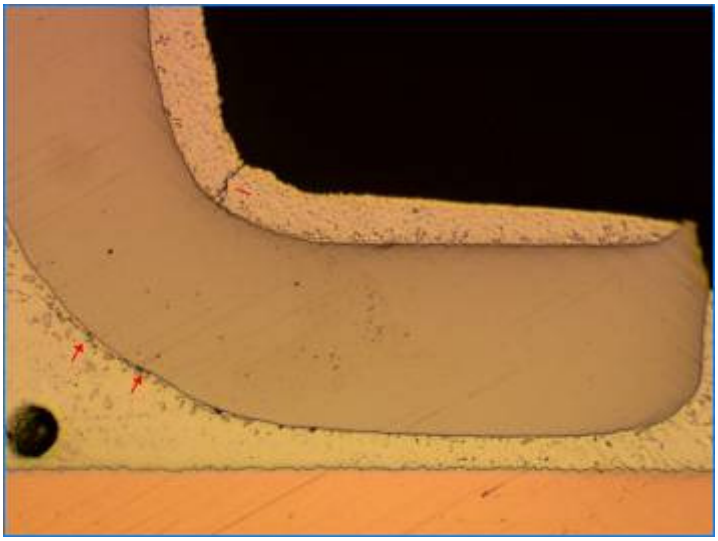

Figure 196: cross section, SN79, U12, right lead solder partial crack, 200xb

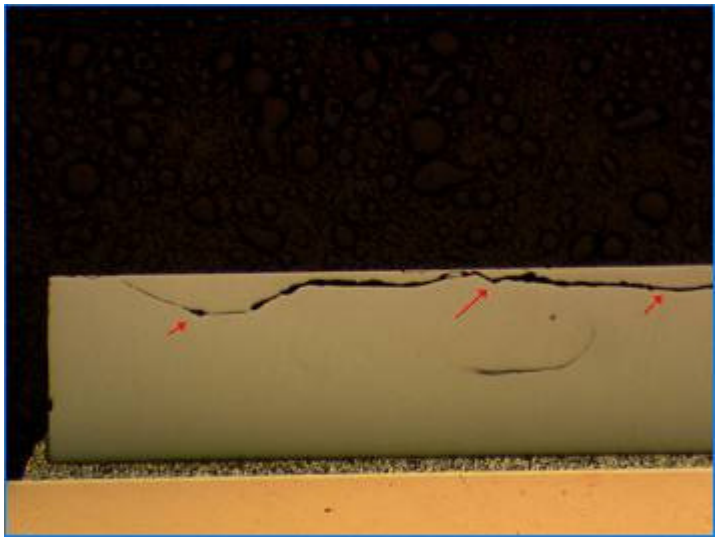

Figure 197: cross section, SN79, U28, comp top crack, 100xa

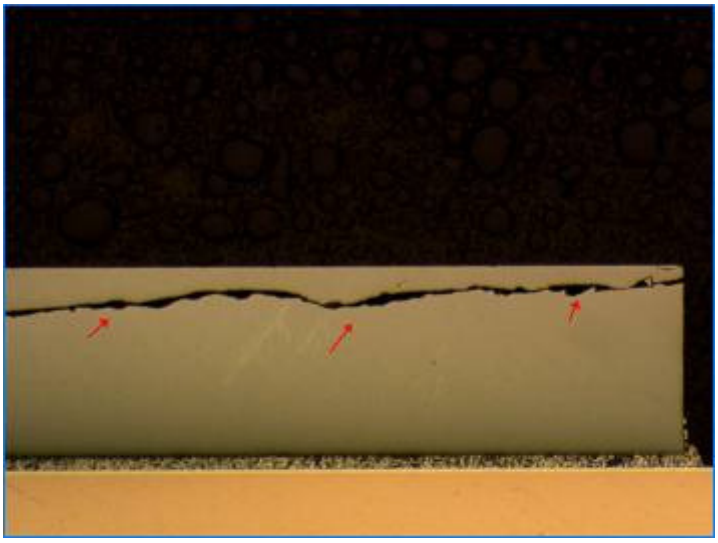

Figure 198: cross section, SN79, U28, comp top crack, 100xb

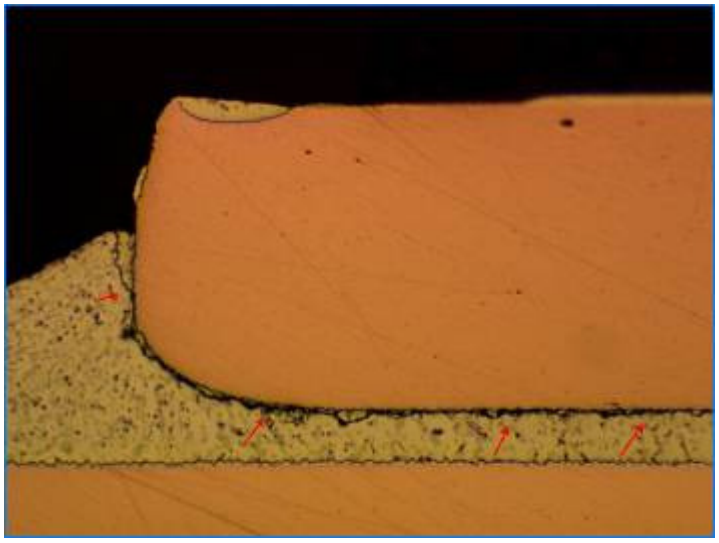

Figure 199: cross section, SN79, U28, left lead solder crack, 200xa

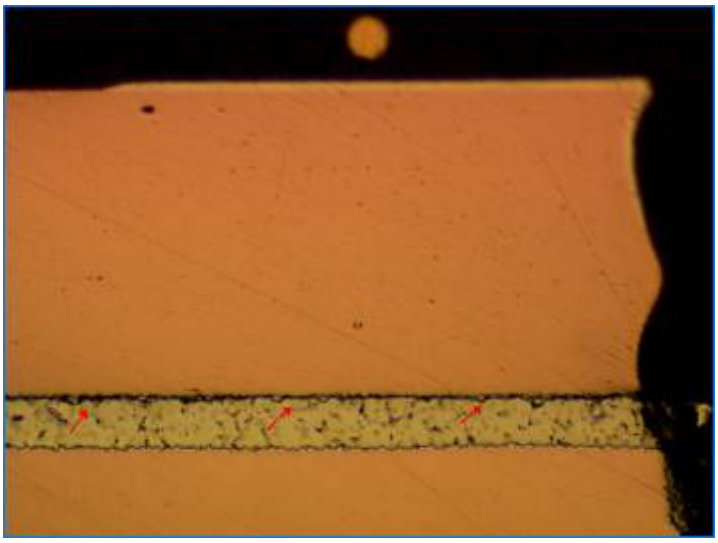

Figure 200: cross section, SN79, U28, left lead solder crack, 200xb

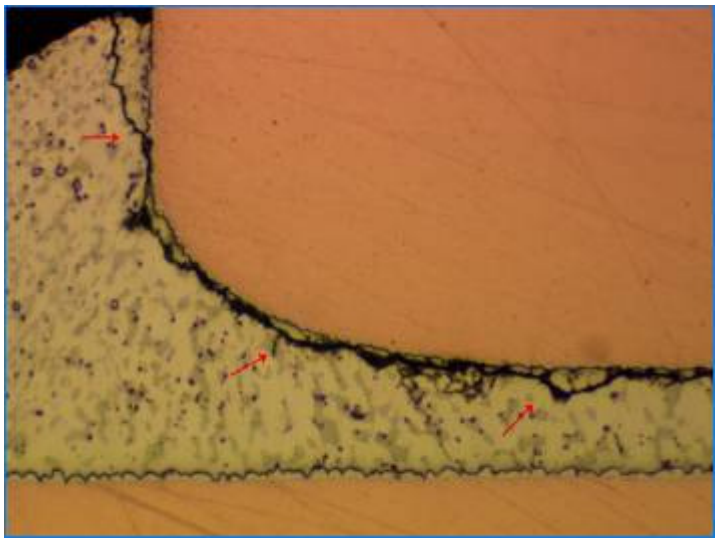

Figure 201: cross section, SN79, U28, left lead solder crack, 400xa

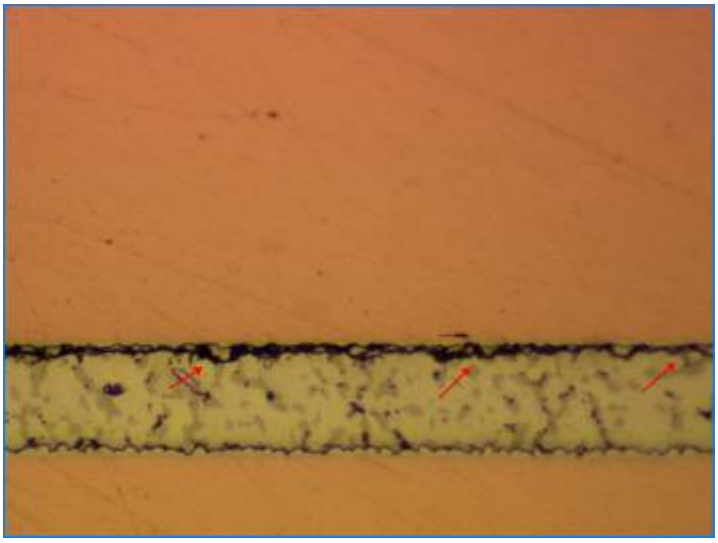

Figure 202: cross section, SN79, U28, left lead solder crack, 400xb

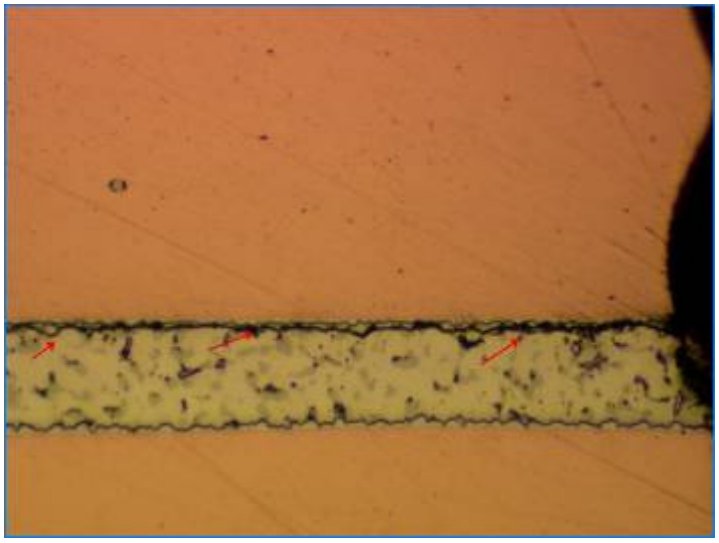

Figure 203: cross section, SN79, U28, left lead solder crack, 400xc

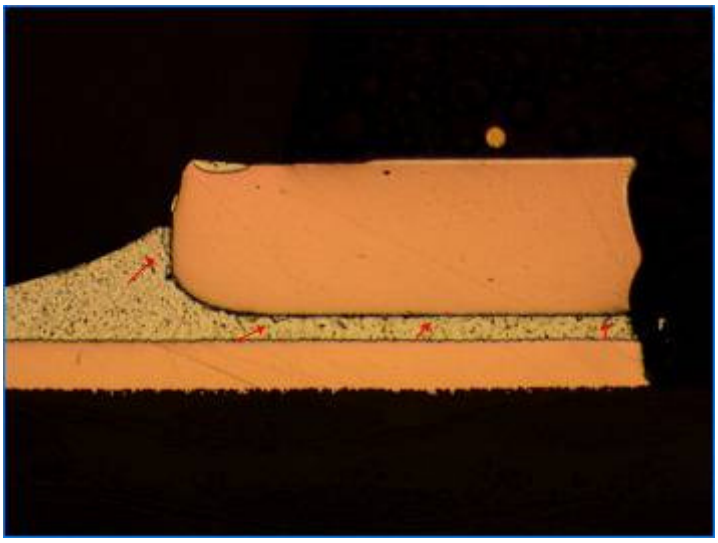

Figure 204: cross section, SN79, U28, left lead solder crack, 100x